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Is approved by the final examining committee:

Wallace E. Tyner
Chair

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Approved by: Gerald E. Shively 7/7/2015

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BENEFITS AND COSTS OF COVER CROPS: A FRAMEWORK FOR DATA COLLECTION AND ANALYSIS

A Thesis

Submitted to the Faculty

of

Purdue University

by

Myriam Bounaffaa

In Partial Fulfillment of the

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of

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LIST OF ABBREVIATIONS

2,4-D	2,4-Dichlorophenoxyacetic acid
ARG	Annual Ryegrass
CC	Cover Crop
CRC	Crimson Clover
CCSI	Conservation Cropping Systems Initiative
CR	Cereal Rye
CSP	Conservation Stewardship Program
CT	Conventional Tillage
CTIC	Conservation Technology and Information Center
EQIP	Environmental Quality Incentives Program
ERS	Economic Research Service
FAO	Food and Agriculture Organization
MCCC	Midwest Cover Crop Council
MCPA	2-methyl-4-chlorophenoxyacetic acid
MU	Mapping Unit
N	Nitrogen
N_2	Nitrogen gas
NCC	Non-Cover Crop
NH_3	Ammonia
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
NT	No-Tillage
OCT	Other Conservation Tillage
OECD	Organization for Economic Co-operation and Development
SAN	Sustainable Agriculture Network
SRF	Soil Ranking Factor
U.S.	United States
USDA	United State Department of Agriculture
WASCOB	Water And Sediment Control Basin

ABSTRACT

Bounaffaa, Myriam. M.S., Purdue University, August 2015. Benefits and Costs of Cover Crops: a Framework for Data Collection and Analysis. Major Professor: Wallace E. Tyner.

Soil erosion and soil compaction can cause a decline in crop productivity and have harmful impacts on the environment. These concerns have raised awareness around the concept of sustainable production. Cover crops are crops that are grown in between cash crop growing seasons for their agronomic and environmental benefits. Researchers have proven the ability of cover crops to reduce soil erosion, reduce soil compaction, increase soil fertility, control weeds and possibly increase cash crop yields. Albeit their numerous benefits, incorporating cover crops into farming systems carry additional costs in terms of time and labor management. In the Midwest, the number of farmers using cover crops is minimal because they perceive the costs to be greater than the benefits. Therefore, the primary objective of this study was to quantify the benefits and costs of cover crops in the Midwest.

To meet the objective, primary data were collected by field and over the last five years. A total of 82 fields was collected, including 52 cover crop fields and 30 non-cover crop fields. The data were related to cash crops, chemical inputs and cover crops. Given the fact that each farm is unique, the data collected resulted in a high variability and heterogeneity in the crop rotation, field soil types and soil slopes. This variability greatly reduced the data that could be used in the quantitative analysis.

From assessing the limitations of our study, we designed a framework for farmers' selection process, data needs, and the analysis needed for future research. We suggested controlling for soil characteristics, crop rotation, and to some extent weather in farmer selection. Only farmers with five years of historic data by field should be included. About 350 fields of data need to be collected in order to perform the

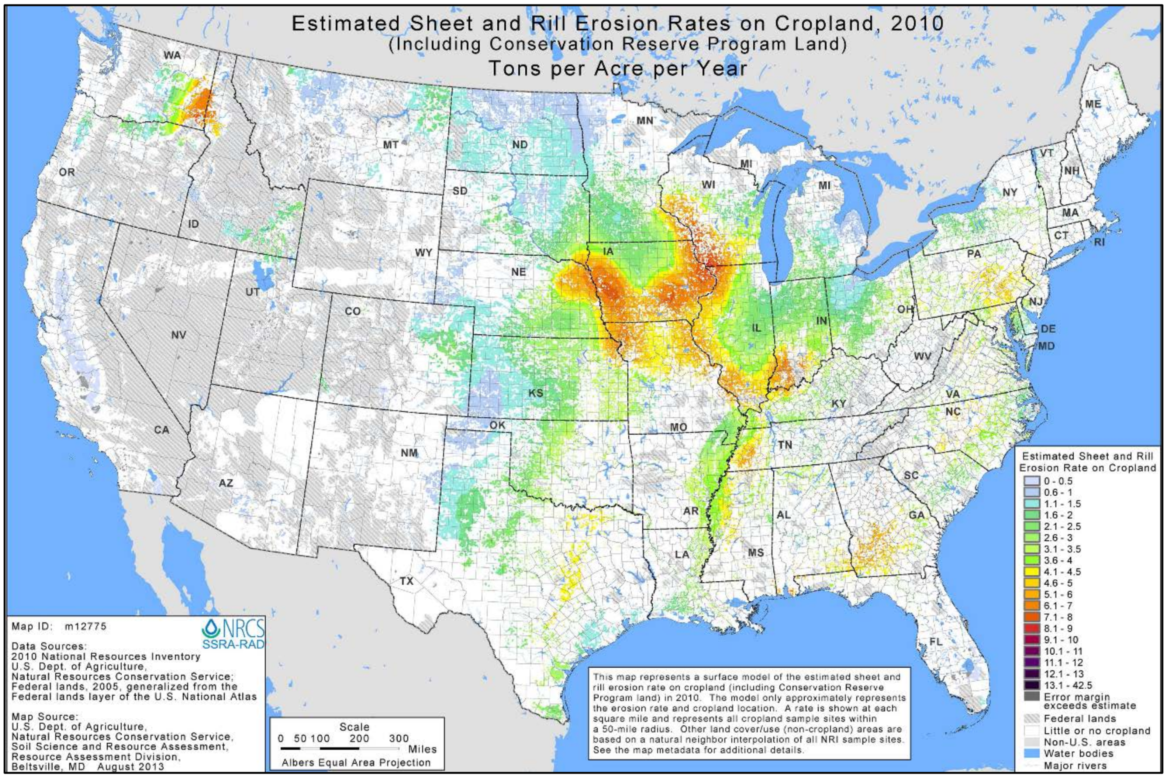
quantitative analysis, which means that 70 farmers need to be recruited. To achieve a quantitative and qualitative increase in the response rate, providing farmers with incentives in the form of financial compensation should be considered. One limitation of this design is that the results are only applicable for the area and the criteria chosen. However, the process can be repeated in any other region.

CHAPTER 1. INTRODUCTION

1.1 Agricultural Concerns in the Midwest

In the United States, farmland, including cropland and pasture accounts for almost 45% of the total land area (USDA, 2007). As defined by the United States Census Bureau, the Midwest consists of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. Also, this region is commonly called the "breadbasket of America.” The Midwest alone accounts for about 39% of the land devoted to agriculture in the United States, with around 68% of the total land area in the Midwest under agriculture (USDA, 2007). This agriculture consists mainly of corn, soybeans, wheat, hogs, dairy and cattle. However, agriculture in the Midwest is facing major soil degradation issues such as soil erosion and compaction, which can reduce future crop performance.

Soil erosion is a process that happens when topsoil is detached and transported elsewhere by water and wind. In the United States, water erosion is predominant in the Midwest, and wind erosion occurs mainly in the Great Plains region (NRCS, 2013a). Soils can endure a certain amount of erosion without unfavorable impacts on soil quality or long-term productivity, as new soil is continually formed to supplant lost soil. This tolerable level is denoted as a T-factor, and it ranges from one to five tons per acre per year. As long as the erosion rate is below T, the soil is deemed to remain productive. Figure 1.1 shows the estimated sheet and rill erosion rates on cropland in the United States. Sheet and rill erosion are both types of water erosion. Sheet erosion happens when the rain runoff removes a thin layer of the soil surface, and rill erosion develops when water begins to cut definite channels or rills. The Midwest seems to be the region where the sheet and rill erosion rates are the highest, with erosion rates above five tons per acre per year, especially in Iowa.



Source: NRCS (2010)

Figure 1.1: Estimated Sheet and Rill Erosion Rates on Cropland in 2010

The impact of erosion is manifold. It tends to remove the less dense soil constituents such as organic matter and nutrients, which are the most productive parts of the soil. A 10-year study conducted in Indiana illustrates the negative impact of soil erosion on crop productivity. On severely eroded soils, corn yields were 9% to 18% lower than those on slightly eroded soils, and similarly soybean yields were 17% to 29% lower (Schertz *et al.*, 1994). Furthermore, the transport of sediments and nutrients by water erosion (sheet, rill, and gully erosion) is a source of non-point pollution and can affect the water quality of streams, lakes and estuaries adversely.

Moreover, eroded soils are inherently low in content of organic matter, which make them susceptible to compaction. In fact, organic matter helps tie soil particles together as aggregates, so they are not easily broken or compressed by tillage or wheel movement. Bigger and heavier field equipment, early planting on possibly wet soil and deep tillage are the main reasons for increased soil compaction. Compaction increases the soil bulk density, resulting in less space for air and water in the soil. Also, compaction has been shown to affect nutrient uptake and may induce nutrient deficiencies for the plant (Wolkowski, 2008). All these effects can lead to a decline in crop performance. It has been reported that compacted fields may experience yield losses of 10 to 20% in some years (Al-Kaisi & Hanna, 2009).

1.2 Cover Crops

To help farmers with these major issues, many conservation practices have been developed, including no-till systems, alternate crop rotations, and cover crop use. Cover crops are grown during periods between regular cash crop productions. Cover crops have been long recognized for their agronomic benefits. These benefits include: reduced soil erosion, decreased compaction, increase in soil porosity and infiltration, increase in organic matter, reduced nutrient and pesticide losses, improved soil microbiology, and removal of excess moisture from wet soils (NRCS, 2013b). A recent survey conducted by the CTIC revealed corn yields increased by 3.2% from the use of cover crops, and similarly soybean yields improved by 4.6% following cover crops (CTIC, 2014).

Therefore, using cover crops can potentially help to resolve some of the main agricultural issues that Midwestern farmers are facing. Despite their numerous benefits, the number of farmers that incorporate them into their farming system is minimal. A survey sent to over 3,500 farmers in Illinois, Indiana, Iowa and Minnesota revealed that almost 90% of farmers in the U.S. Corn Belt have not integrated cover crops into their farming systems in the past five years (Singer, 2007). The low number of farmers using cover crops has brought a lot of attention to the question of why they are not used more widely in the Midwest. Some disadvantages of cover crops resulting from the survey are that they are too costly, and too much time is involved in the planting and termination process. Also, some farmers revealed that they are not using cover crops because of the lack of information about them.

1.3 Objective

Soil erosion and soil compaction are threatening the agricultural productivity of the Midwest farms. Farmers are reluctant to incorporate cover crops in their system, albeit their numerous potential benefits. The reasons behind this decision remain unclear. There is a wide perception that cover crop benefits are substantial, but they have not been quantified in the literature. Therefore, the aim of this study is to evaluate and quantify the long term benefits and costs associated with cover crops under different management regimes. The analysis considers field data from farms who practice and do not practice cover crops in order to determine to what extent they are different. Each field is considered as a data point, and the analysis includes a comparison controlling for some variables such as tillage regime, soil type, and seed biotech traits. One of the major issues to be faced in this study is that each farm is unique, and in the end, we may not be able to see a clear pattern of differences emerge between cover crop and non-cover crop farms and fields given the limited number of farms/fields. However, at a minimum, we should be able to better characterize the data and analysis that will be needed in future studies to better quantify the benefits and costs of cover crops.

1.4 Organization

Chapter Two provides a literature review on soil degradation factors and consequences, cover crop advantages and disadvantages, common cover crop species, the current use of cover crops in the United States and a review of past studies on the economics of cover crops. Chapter Three presents the data and methods used to conduct the analysis. Chapter Four presents the results of the data collected and the framework design suggested for future research on the economics of cover crops.

CHAPTER 2. LITERATURE REVIEW

The focus of this literature review is on the environmental and economic consequences of cover crops. One of the important impacts of cover crops is the reduction in soil erosion. This review also describes a selection of cover crop species and addresses some cover crop advantages and disadvantages. Further, historical use of cover crops and possible reasons for the current use in the United States is discussed. Finally, previous research on the economics of cover crops and on comparison of management practices is reviewed.

2.1 Soil Degradation: Factors and Consequences

Soil degradation is a worldwide issue that has harmful repercussions on soil productivity and the environment. This process is associated with deterioration of soil health status that decreases the soil's ability to provide normal goods and services (FAO, 2015a). There are three major manifestations of soil degradation: physical, chemical and biological. An increase in bulk density reduces soil structure, which leads to accelerated wind and water erosion. Moreover, a change of the chemical properties of the soil can generate soil acidification and nutrient leaching. Finally, the decline in soil biodiversity results in the reduction in humus quality and quantity. Natural factors such as climate and vegetation, but also human influence are the main source of soil degradation. All these processes lead to a reduction of biomass productivity, water pollution and decline in air quality (Lal, 2001).

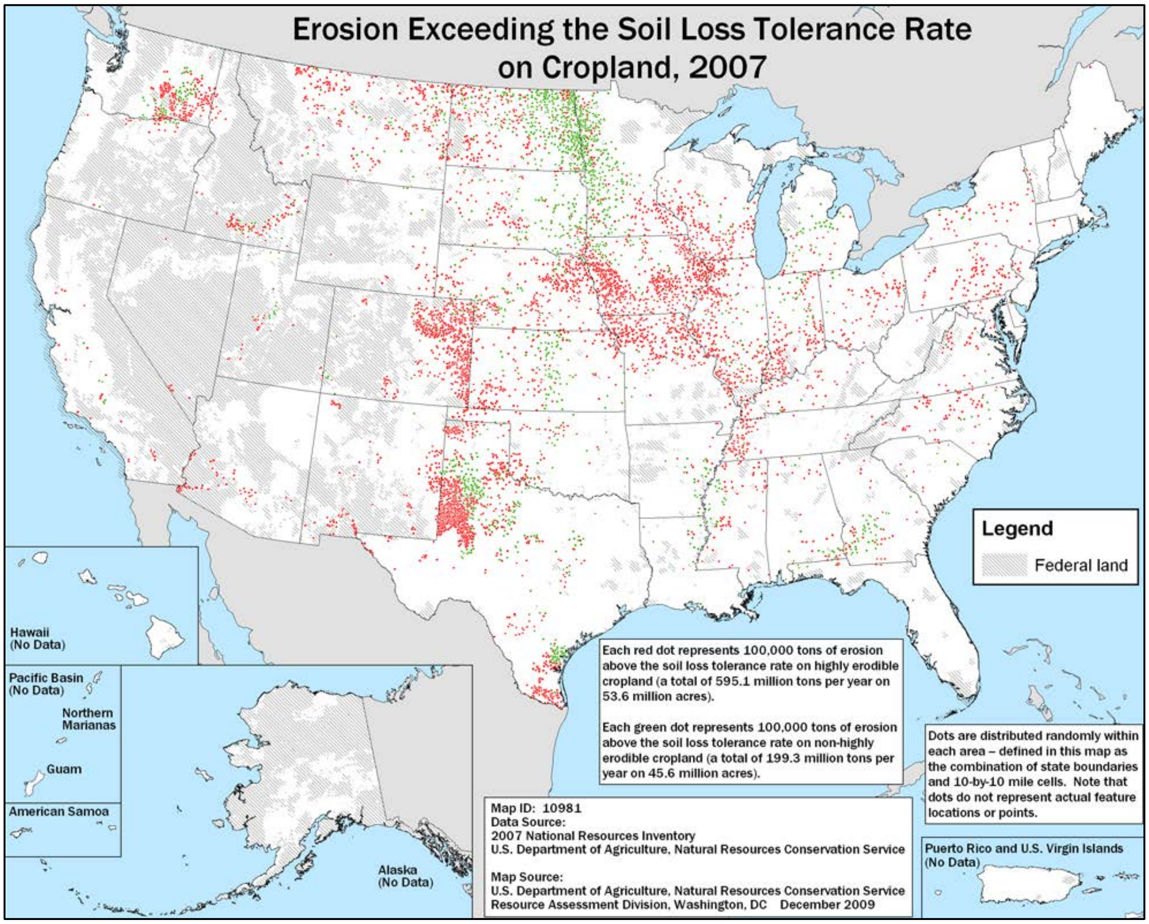
In the next two sections, we will review the literature on the consequences of soil erosion and soil compaction. Soil erosion is the major manifestation of soil degradation. Human influence such as an increase in tillage over the years has increased soil loss and runoff, which has had on site and off site negative impacts.

2.1.1 Soil Erosion

Soil erosion relates to the detachment and transportation of soil particles from the surface by two major forces: water and/or wind. Symptoms of water erosion may be identified when runoff water develops channels or rills. If erosion is not controlled, rills grow to gullies or ravines. Wind erosion can be identified by dust clouds or soil accumulation along fence lines (NRCS, 2012). One of the biggest historical manifestations of wind erosion is the "Dust Bowl" of the 1930s in the Great Plains region of the United States. A combination of severe drought, deep plowing and deep grazing caused the soil particles to detach from the soil and create clouds of dust transported by wind over several states (Cook *et al.*, 2009).

Water and wind erosion are estimated in the Unites States by means of a periodic Natural Resources Inventory (NRI). The survey findings of the 2010 NRI show that estimated sheet and rill erosion on cropland is predominant in the Midwestern states, especially in Iowa where it reached 5.26 tons per acre per year. The largest cropland region affected by wind erosion is in the Great Plains extending from Texas to Canada. In Colorado, 9.38 tons per acre per year and 16.43 tons per acre per year in New Mexico of lost soil on cropland were estimated to be caused by wind erosion (NRCS, 2013a).

Soil erosion has always been a natural process, and soil formation to replace lost soil is a slow process. However, human activities, such as deforestation, intensive agricultural practices, and construction projects, have increased soil erosion over the years. The soil loss tolerance factor, also called the T factor, has been established by the NRCS as the maximum rate of annual soil loss that will permit crop productivity to be sustained economically and indefinitely on a given soil. The primary use of the T-factor is evaluating the effectiveness of erosion control measures on farmland. T-factors range from one to five tons per acre per year. Figure 2.1 shows the erosion exceeding the soil loss tolerance rate on cropland in 2007 (NRCS, 2010). This map clearly indicates that wind and water erosion are degrading the Great Plains and Midwest regions.



Source: NRCS (2010)

Figure 2.1: Areas with High Soil Erosion in 2007

The soil particles involved in soil erosion are components of the topsoil. This is the upper part of the soil, usually the top two to eight inches, that is ordinarily rich in organic matter (Franzmeier *et al.*, 2009). Erosion involves two types of effects: on-site and off-site effects. On-site erosion impacts are effected at the place where the soil is detached. Since the main place of on-site erosion is at the farm, it is also called the on-farm effect.

The main on-site impact is the decline in soil quality. As organic matter decreases from loss of topsoil, soil aggregate stability and ability to hold moisture decline, resulting in reduced yield potential. Several studies have documented the impacts of soil erosion on yield performance. A 10-year study estimated the effects of soil erosion on corn and soybean yields on three Indiana soil series: Corwin, Miami, and Morley. In addition, three degrees of erosion were studied: slight, moderate and severe erosion. The results showed that corn yields on severely eroded soils were 9% to 18% lower than those on slightly eroded soils, and similarly, soybean yields were 17% to 29% lower (Schertz et al., 1994). Along similar lines, a group of researchers estimated crop production losses due to erosion by combining the results of 90 field-based studies in the United States and Canada. The analysis focused on the impact, by soil order, of soil erosion on four crops: corn, wheat, soybeans and cotton. The annual amount of production decline resulting from erosion in the United States was estimated at 229,000 Mega grams (Mg) for corn (9,015,748 bushels), 54,000Mg for wheat (1,983,835 bushels), 61,000 for soybeans (2,241,000 bushels) and 1,900 Mg for cotton (41,887 pounds). By using the 2000 prices, these losses represents a total value of US$37.9 million for the selected crops and soil orders (Den Biggelaar *et al.*, 2001).

The off-site problems arise when lost soil is transported considerable distances by water or wind. The movement of sediments, nutrients, and pesticides into watercourses can lead to the disruption of the ecosystems of lakes and contamination of drinking water. The off-site effects are various, and they are related to the processes of sedimentation and silting of water resources. These processes lead to significant repercussions on society, such as increased costs of generating electricity and an increased cost of treating water for urban use. The biological impact of erosion is substantial as aquatic ecosystems can be seriously harmed by sediment and other erosion related contaminants (Clark, 1985). Also, siltation of reservoirs and dams reduces water storage, increase the maintenance cost of dams, and shortens the lifetime of reservoirs. The offsite damage from wind erosion in the United States was estimated to cost nearly $10 billion each year (Pimentel *et al.*, 1995).

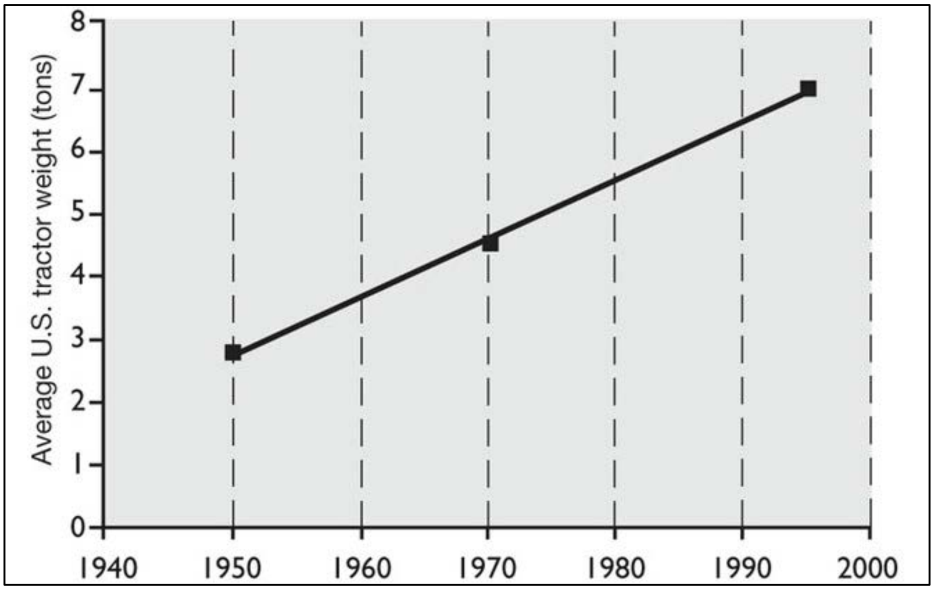
Another agent in soil degradation is the increase in bulk density of the soil resulting in soil compaction. The next section will define soil compaction and review its consequences on crop productivity.

2.1.2 Soil Compaction

Soil compaction is defined as the “movement of soil particles closer together by external forces, such as rain, livestock traffic or the weight of farm equipment”

(Franzmeier et al., 2009). As a result, the volume of pores among soil particles decreases as compaction increases.

A major source of compaction is the increase in weight of farm machinery in recent decades. Figure 2.2 shows the net increase in U.S. tractor weight over the past several decades.



Source: Soane and Van Ouwerkerk (1998)

Figure 2.2: Tractor Weight Increase over the Years

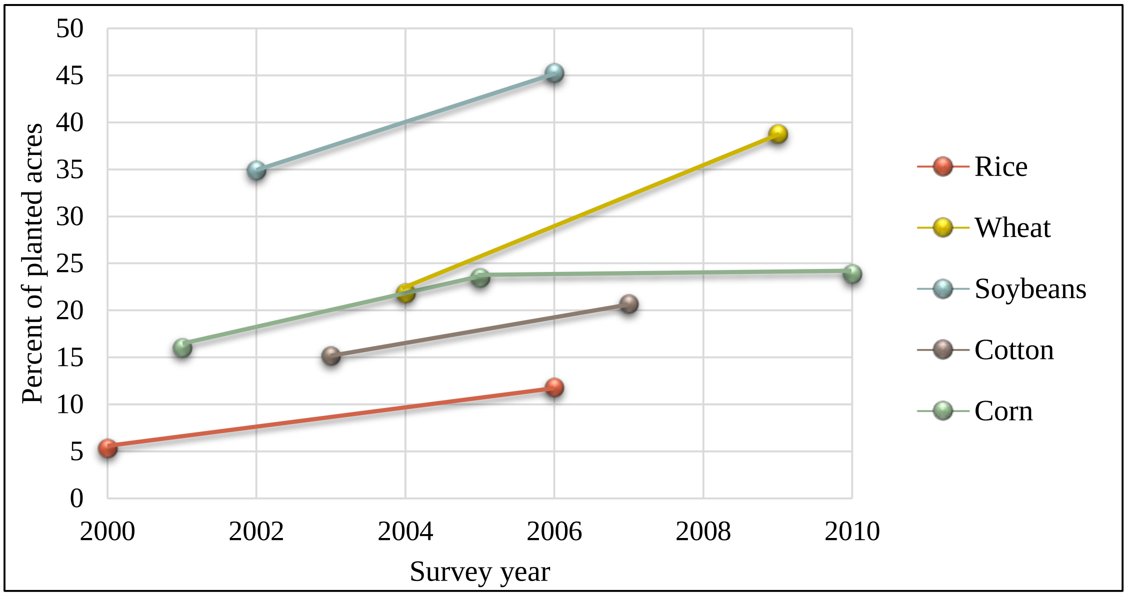
Therefore, the threat of soil compaction is greater today than it has been in the past. The main effect of soil compaction is the reduction of crop productivity. Radford *et al.* (2001) conducted a 6-year experiment to quantify the wheat, sorghum and corn response to annual compaction treatments on a Vertisol. The compaction treatments were a combination of different machinery weight and soil water content. The results suggested that compaction treatment reduced seedling emergence, grain yield, soil water storage, and crop water use efficiency. The mean reduction in yields compared to the control (no compaction) was 23% for wheat, 13% for sorghum, and 1% for corn.

Soil erosion and soil compaction are only two of the physical manifestations of soil degradation. Recognizing that soil degradation is a serious threat to crop productivity and the environment, conservation practices were developed in the past few decades to alleviate the effects of soil degradation. In the next section, we will define conservation agriculture and describe its components.

2.2 Rise of Conservation Agricultural Practices

Projections of world population growth coupled with a degradation of resources raise concerns about the ability of global agriculture to meet future demand. The new concept of “sustainable production intensification” identifies the need for a productive and remunerative agriculture, which at the same time preserves and improve the natural resource base and the environment (FAO, 2011). As wisely put by Nobel Peace Prize winner Norman Borlaug in 2008:“Over the next 50 years, the world’s farmers and ranchers will be called upon to produce more food than has been produced in the past 10,000 years combined, and do so in environmentally sustainable ways”.

FAO defines conservation agriculture as “an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment” (FAO, 2015b). Minimum mechanical soil disturbance, also called conservation tillage, is one of the components of conservation agriculture. Conservation tillage is defined as a cropland system that leaves at least 30% or more of the soil covered with crop residue after planting (Rust & Williams, 2010). No-till, Strip-till, Ridge-till, and Mulch-till are types of conservation tillage. In the United States, conservation tillage has been increasing over the years. As illustrated in figure 2.3, the percentage of planted acres for a selection of cash crops under no-till has been increasing from 2000 to 2010.



Source : ERS (2013)

Figure 2.3: Percent of Planted Acres under No-Till Systems for Selected Crops, from 2000 to 2010

Another component of conservation agriculture is the diversification of crop species grown in a crop rotation and the adoption of permanent organic soil cover such as cover crops. The remainder of this chapter will explore the use of cover crops and the extent to which their use can be beneficial in alleviating soil degradation effects.

2.3 Cover Crops

In this section, we will define cover crops and provide a description of several cover crop species.

2.3.1 Cover Crops Defined

Reeves (1994) defined cover crops as "crops grown specifically for covering the ground to protect the soil from erosion and loss of plant nutrients through leaching and runoff." The author also explains that cover crops are grown off-season with an annual planting. A more recent definition of the Organization for Economic Co-operation and Development (OECD, 2001) specifies that a cover crop is an intermediate crop that can be removed by the use of selective herbicides. As defined by the NRCS, cover crops include grasses, legumes, or other herbaceous plants established for seasonal cover and conservation purposes (NRCS, 2013b). Teasdale (1996) defines winter annual cover crop as a crop that is planted in late summer or fall, becomes established before winter, and produces the most biomass during early spring before planting a summer crop. The next section will describe a selection of cover crop species.

2.3.2 Crop Species

There are many species of cover crops, each with its advantages and disadvantages. Dabney *et al.* (2001) considered that a farmer's choice to include cover crops in cropping systems is based on the perceived balance between advantages and disadvantages summarized in table 2.1.

Table 2.1: Advantages and Disadvantages of Cover Crops

Advantages	**Disadvantages**
Reduce soil erosion	Must be planted when time (labor) is limited
Increase residue cover	Additional costs (planting and killing)
Increase water infiltration into soil	Reduce soil moisture
Increase soil organic carbon	May increase pest populations
Improve soil physical properties	May increase risk of diseases
Improve field trafficability	Difficult to incorporate with tillage
Recycle nutrients	Allelopathy
Legumes fix nitrogen	
Weed control	
Increase the population of beneficial insects	
Reduce some diseases	
Increase mycorrhizal infection of crops	
Potential forage harvest	
Improve landscape aesthetics	

Source: Dabney et al. (2001)

Several tools and resources are available that provide information on cover crop selection. The Sustainable Agriculture Network (SAN) published a guide named "Managing cover crops profitability" with detailed information regarding cover crops for multiple regions in the United States (SAN, 2007). The following sections rely heavily on this guide. We will describe a selection of legumes, non-legumes and mixes of cover crops and address some of the advantages and disadvantages of each. Since corn and soybean rotation is predominant in the Midwest, the cover crops described are winter cover crops.

2.3.2.1 Legumes

Legume crops are unique for their ability to fix atmospheric nitrogen for its use. Approximately 80% of the atmosphere is nitrogen gas (N_2). N_2 is unusable by most living organisms, but most of them use the ammonia (NH_3) form of nitrogen. Biological nitrogen fixation is defined as “the process that changes inert N_2 to biologically useful NH_3”. This process is completed by a bacteria called *Rhizobium*. The bacteria invade the roots, and the nitrogen fixation starts the formation of nodules. The partnership between the plant and the bacteria result in the production of NH_3 that is absorbed by the plant (Lindemann & Glover, 2003). There is a wide variety of legume cover crops, including berseem clover, cowpeas, medics, red clover and others. Some of the most popular legume cover crops are crimson clover and hairy vetch. Next, we will discuss some advantages and disadvantages of each cover crop.

Crimson clover (*Trifolium incarnatum*) is a winter annual or summer annual legume cover crop. During the fall and winter, it grows slowly, and the leaves form a low rosette clump. Crimson clover survives heat and drought conditions but does not tolerate flooding or ponding. The main roles of crimson clover include nitrogen-fixing, soil builder, erosion prevention, reseeding inter-row ground cover and forage. Moreover, crimson clover has a good establishment, can be terminated easily by tillage, and can also be mown killed. One main disadvantage of crimson clover is that it is a secondary host to plant pests like insects and nematodes (SAN, 2007)

Similar to crimson clover, hairy vetch (*Vicia villosa*) is a winter annual or summer annual legume cover crop. Hairy vetch is described as a trailing or climbing crop, with a shallow root system. Stems may grow three to seven feet long. Branched tendrils terminate leaves. Hairy vetch is productive on somewhat poorly drained to well-drained soils. Compared to crimson clover, hairy vetch delivers heavy contributions of mineralized nitrogen readily available to the following cash crop. In addition, hairy vetch acts as a soil conditioner and as an early weed suppressor. Finally, it provides a good ground cover for erosion control during winter and spring (SAN, 2007). However, hairy vetch contains up to 25% of seeds that do not immediately germinate. One of the disadvantages is that the seed can come up in future years as a weed in winter small grains (Duiker *et al.*, 2010)

2.3.2.2 Non-Legumes

Non-legume cover crops include several families such as grasses and brassicas. In the next section, we will highlight the specific qualities and disadvantages of annual ryegrass, oats, cereal rye, and radish.

Annual ryegrass (*Lolium multiflorum*), also known as Italian ryegrass, is a turf grass with a dense, shallow root system. It establishes quickly, even in poor, rocky, or wet soils and tolerates some flooding once established. For a winter annual use, annual ryegrass can be seeded from midsummer to early fall, and then killed a few weeks before planting the subsequent cash crop. Annual ryegrass has a rapid aboveground growth with about 4,000 to 8,000 pounds of dry matter per acre on average over the full field season. The main disadvantage is that annual ryegrass has the potential to become a weed in the crops that follow (SAN, 2007).

Like annual ryegrass, Oats *(Avena sativa)* are part of the Grass family. Oat is an annual cereal that grows two to five feet tall. Like most small grains, oats have a high acidity tolerance and can be grown in soils with a pH as low as 5.0. Some benefits of oats include suppressed weeds, erosion prevention, excess nutrient scavenging and additional biomass. However, if planted too early in the fall, it can be susceptible to leaf diseases and insect pests that can be transmitted to the following cash crop (SAN, 2007).

Not to be confused with annual ryegrass, cereal rye (*Secale cereale*) or winter rye, is also a cool season annual cereal grain that grows three to six feet tall with flat leaf blades and dense flower spikes. The grain is relatively large, typically around a half inch long. Like annual ryegrass and oats, cereal rye is a good nutrient catch crop and weed suppressor. Moreover, cereal rye fits many rotations including corn, soybeans, fruits, or vegetables. Cereal rye can also be susceptible to leaf diseases and insect pests (SAN, 2007).

Forage radish (*Raphanus sativus L. var. niger J. Kern*) and oilseed radish (*Raphanus sativus L. var. oleiformis Pers*) are both fall-seeded brassicas that are used as cover crops. They are most helpful in no-till systems where their large roots can help reduce soil compaction and increase soil moisture. The root decomposes in the spring, leaving large, deep holes in the soil that leads to a better water and air infiltrations. Moreover, the subsequent crop roots can better penetrate the dry and hard soil in the summer (Weil & Williams, 2003). The main difference between these two types of radishes is that forage radish has a very large taproot. The radish has good heat and drought tolerance, but a very low tolerance for flooding. One of the reported disadvantages is the bad odor of the decomposition of radishes in spring (MCCC, 2014).

2.3.2.3 Cover Crop Mixes

Mixtures of cover crops can optimize the benefits of their use. For example, a mix that includes annual ryegrass, crimson clover, and radishes both produces and scavenges nitrogen. Another mix that includes cereal rye, hairy vetch, and radishes maximizes green manure production and nitrogen fixation. Also, cover crop mixtures can reduce risk because each crop may respond differently to soil, pest, and weather conditions. However, cover crop mixtures can make management more difficult. For example, some cover crops do not have the same time of termination, and the choice of herbicides may be limited when you mix legume and non-legume cover crops (SAN, 2007).

As we noticed in the description of cover crop species, cover crops are primarily planted for their benefits to the soil or environmental quality and not for harvest. The following section presents the results of existing research on cover crop advantages.

2.4 Cover Crop Advantages

In this section, we will review the major studies that demonstrated how cover crops can reduce soil erosion and compaction, increase soil fertility, control weeds and increase cash crop yields.

2.4.1 Reduction of Soil Erosion

The classic use of cover crops is to reduce wind and water erosion, which consequently maintains soil quality and structure. Zhu *et al.* (1989) studied the impact of a selection of winter cover crops following soybeans on soil erosion in Missouri. The winter cover crops considered were chickweed, Canada bluegrass, and downy brome. The study compared no-till plots with and without cover crops. The control was no-till soybean without a cover crop. The results showed that winter cover crops increased soil cover by 30 to 50% during the critical erosion period of late spring to early summer. Compared to the control, mean annual soil losses from the chickweed, downy brome, and Canada bluegrass were decreased by 87%, 95%, and 96% respectively (Zhu et al., 1989). Another study looked at the impact of vetch and wheat cover crops on cotton in three tillage systems: no-till, reduced-till and conventional-till. One principal result of the study was that in a conventional till system, incorporating cover crops into the farming system reduced annual soil loss by 73% (Mutchler & McDowell, 1990). Kaspar *et al.* (2001) looked at the impact of oat and rye cover crops on erosion in Iowa in 1997 and 1998. The results suggested that rye decreased rill erosion, compared with the control, by 93% and 86% in 1997 and 1998, respectively, and oat cover crop decreased rill erosion by 64% in 1997 and 42% in 1998.

2.4.2 Soil Compaction Effects

Research has shown that cover crops could alleviate soil compaction effects. A study by Weil and Williams (2004) used a minirhizotron camera to monitor the root growth of cover crops and the following soybean crop during the 2002 growing season. The cover crops considered were canola, oilseed radish, forage radish, and cereal rye. As can be seen in figure 2.4, the pictures taken by the minirhizotron camera suggested that soybean roots followed channels made by the previous canola cover crop. They speculated that the cash crop could gain access to the subsoil when the compacted layer is driest, and penetration resistance is highest (Williams & Weil, 2004). Later, Chen and Weil (2009) evaluated the penetration of compacted soils by roots of three cover crops: forage radish, rapeseed and cereal rye. Three compaction levels (high, medium, and no compaction) were created by wheel trafficking. The experiments were conducted on two adjacent fields with two different soil types and both under no-till management. In the first field, the results indicated that forage radish had more roots than rye at 10 to 50 cm depth and had more roots than rapeseed at 15 to 30 cm depth in case of high compaction. In the same scenario, rapeseed had more roots than rye at 25-35 cm depth. In the second field, forage radish had 1.5 times as many roots as rye under high compaction.

Source: Weil and Williams (2004)

Figure 2.4: Minirhizotron Images showing Canola Roots Growing in May(left) and Soybeans Roots Observed in August (right)

2.4.3 Increased Soil Fertility

As previously discussed, a benefit of legume cover crops is the legume's natural ability to fix atmospheric nitrogen. When the aboveground plant residues, roots, and nodules gradually decompose, the nitrogen is released. Usually, about two-thirds of the nitrogen fixed by a legume cover crop becomes available for the next crop (NRCS, 1998b). A study looked at the nitrogen (N) availability of three cover crops grown following corn: "tibbee" crimson clover, an ineffective-nodulating crimson clover, and a rye. No cover crop grown following corn was the control. Results suggested that the two crimson clovers produced significantly higher biomass and total N compared with rye, which significantly improved corn yields (Torbert *et al.*, 1996). Other non-legume cover crops, especially brassica or grasses, can trap or scavenge over 40 pounds of residual nitrogen from the soil originating from fertilizer or soil organic matter mineralization (Kladivko & Fisher, 2011).

Several studies evaluated the impact of legume and non-legume cover crops on soil fertility. Blevins *et al.* (1990) conducted field experiments to determine the fertilizer N equivalency of hairy vetch, bigflower vetch, and rye to no-tillage corn and grain sorghum. A fallow treatment consisting of stalk residue was used as a comparison. Fertilizer N rates for corn were 100 kg per hectare from 1980 to 1983 and 170 kg per hectare from 1984 to 1987. The results showed that estimated fertilizer-N equivalency of the hairy vetch in the corn experiment was 75 kg per hectare, and bigflower vetch was 65 kg per hectare. Fertilizer-N equivalency values in the grain sorghum experiment were estimated to be 125 kg per hectare for hairy vetch and 135 kg per hectare for bigflower vetch, which represents a significant portion of the fertilizer N rates. Another group of researchers conducted a 2-year field experiment to determine dry matter accumulation, chemical composition, and N release from rye, crimson clover, hairy vetch, and two mixes of rye-crimson clover and rye- hairy vetch. Results suggested estimates of N released from cover crop residue were 24 kg per hectare for rye, 60 for crimson clover, 132 for hairy vetch, 48 for rye-crimson clover, and 108 for rye-hairy vetch. These numbers only show a small reduction in N release from a legume cover crop and a mix of legume/grass cover crops (Ranells & Wagger, 1996).

2.4.4 Weed Control

Previous research has shown that cover crops are a good weed control mechanism. Teasdale (1996) described the contribution of cover crops to managing weeds in sustainable agricultural systems. All plants use photosynthesis to grow and need a certain amount of light to do it. The use of cover crops provides shade to the soil and, therefore, reduce the quantity of light available to the potential weed. In addition, since cover crops cover the soil, soil temperatures are reduced, which delays the emergence of weeds. Finally, many cover crops are allelopathic, which means they have the ability to release toxins that are presumed to inhibit weed germination and growth in natural environments. Cover crop residue increases soil moisture by increasing infiltration and by decreasing evaporative moisture loss. This will prevent the weeds from germinating if the soil is saturated, but also increase their emergence if it's a drought year (Teasdale, 1996).

A 2-year study conducted in Michigan examined the influence of annual legume cover crops on weed populations. The cover crops considered were: two annual medic species and barrel medic, berseem clover and medium red clover. These cover crops were seeded following wheat in a no-till wheat-corn rotation. Compared with no cover control, the results suggest that the weed density was between 41 to 78% lower following most cover crops (Fisk *et al.*, 2001).

2.4.5 Impact on Cash Crop Yields

One of the most interesting potential benefits for farmers is the increase in cash crop yields. Several studies looked at the effect of cover crops on increasing cash crop yields, but the results were only valid for the specific cover crop, crop rotation and under the specific environmental conditions of each experiment. However, a study conducted by Miguez and Bollero (2005) used meta-analysis to quantify the effects of winter cover crops on corn yield based on 36 published papers in the United States and Canada. Results suggest that bicultural and grass cover crops both had an overall positive effect on corn yields. Bicultural cover crops increased corn yields by 21%. Legume cover crops increased corn yields by37% when no nitrogen was applied. However, the grasses had no effect on corn yields.

The Conservation Technology and Information Center (CTIC) and partners designed a cover crop survey that was sent to farmers nationwide. The survey included various questions on the farmer's perception of cover crops. One question looked at the difference in cash crop yield: "On land where you planted cover crops in 2012, how did your 2013 corn crop perform compared to other, similar acreage where no cover crops were used?" The results suggested that corn yields increased by 3.2% from the use of cover crops, and similarly soybean yields improved by 4.6% following cover crops (CTIC, 2014).

As reviewed in the previous section, cover crop benefits are numerous. However, they require additional management and carry several risks. Also, cover crops represent an additional cost for a non-cover crop farmer who might decide to plant cover crops. The next part is a review of the common disadvantages of cover crops.

2.5 Cover Crop Disadvantages

Additional costs for cover crops include the establishment cost and the termination cost.

The establishment cost depends on the cost of the cover crop seed and the cost of the seeding method. Different seeding methods exist in the United States, including drilling, broadcasting, and aerial seeding. Drilling is considered as one of the most reliable seeding methods due to good seed-to-soil contact. One disadvantage of this method is that seeding is delayed until after harvest of the cash crop. The seed may also be broadcast, which means that the seed is scattered mechanically on the soil surface. Aerial seeding involves sowing seeds by spraying them from an airplane or helicopter. This method is commonly used by farmers considering it's an opportunity to inter-seed the cover crop into corn or soybeans before harvest time (Kladivko, 2011). This is especially true in northern parts of the Corn Belt. In areas further south, cover crops can be planted after harvest.

Another required management is that farmers who are using cover crops have to plan in advance the timing and method of cover crop termination. Cover crops may be killed naturally in the winter (winterkilling), and others have to be mechanically or chemically killed before the planting season of the cash crop. Some cover crops may be difficult to be chemically killed. A field study was conducted to compare different herbicide types (paraquat, glyphosate, SC-0224, and HOE-39866) on Subterranean clover, crimson clover, and hairy vetch cover crops. For the early application, subterranean clover control with paraquat at 1.1 kg/ha was approximately 80% effective regardless of spray volume but was no higher than 45% when applied at 0.6 kg/ha. Glyphosate and SC-0224 applied early provided poor control of all legume cover crops while HOE-39866 gave excellent control. The results suggest that if cover crops are difficult to control, repeated applications may be necessary, which represents additional financial and time costs to the farmer (Griffin & Dabney, 1990). Other than the type of herbicide used, the cover crop growth stage, the weather conditions at application and the subsequent cash crop to be planted are other factors that farmers have to consider when chemically terminating cover crops. Furthermore, mechanical termination of cover crops can be done by tillage, mowing, or roller crimping the crop. Tillage can effectively terminate cover crops, but can also reduce some of the benefits of the cover crops such as soil erosion control (Kladivko, 2011).

Another factor to take into account is that producers have to terminate the cover crop before the deadline listed in the NRCS termination cover crop guidelines to be able to ensure a successful crop following a cover crop (NRCS, 2014). The termination guidelines show the different zones in the United States where cover crops have to be terminated at different dates. For example, in Indiana and Illinois, cover crops can be terminated at or within five days after planting the cash crop. In North Dakota, cover crops have to be terminated 15 days or earlier prior to planting the crop. Farmers can see this insurance requirement as an additional constraint.

To sum up, cover crops show various benefits to improve soil health, reduce soil erosion and soil compaction, and may increase yields. However, these crops require additional management and costs in order to include them in the farming system. In the next section, we will review the literature on the current use of cover crops in the United States.

2.6 Current Use in the United States

The use of cover crops in the United States is minimal. In 2012, 3% of the total cropland acres was planted in cover crops. However, the share of cover crops by state varies. In Maryland, 23.5 % of the cropland was planted with cover crops in 2012. The states with the lowest share of cover crop acres (0.8%) are North Dakota, South Dakota and Montana. In the Midwest, cover crops were planted on 2% of the total cropland acres. Michigan and Wisconsin are the states with the highest share of cover crop acres (5.7%) followed by Indiana with 4.7% of the cropland planted with cover crops in 2012 (USDA, 2014).

A survey conducted by Singer (2007) attempted to quantify cover crop use and identify the factors associated with their adoption in the U.S. Corn Belt (Illinois, Indiana, Iowa, and Minnesota). The survey was mailed to 3,500 farmers in the four states. A total of 1,096 usable surveys was completed. The overall response rate for the four states was 36.1%. Of those that responded, 18% indicated that they had used cover crops in the past, and 11% reported using cover crops in the past five years. Corn Belt farmers believe that cover crops are most effective at reducing soil erosion (96%) and increasing soil organic matter (74%).

Much research on the reasons why the number of farmers using cover crops is minimal has been done. Lichtenberg (2004) used a revealed preference approach to study the responsiveness of farmers to using conservation practices under a cost-sharing program in Maryland. He found that farmers who plant cover crops tended to employ other conservation practices. Bergtold *et al.* (2010) sent a mail survey to Alabama crop producers to ask questions regarding their experience with growing cover crops. The survey response rate was about 28%. The study revealed that a proof of an increase in yields is necessary to convince farmers to grow cover crops. Also, farmers will most likely continue growing cover crops if they have done so in the past. Finally, environmentally conscious farmers likely view cover crop planting as very important (Bergtold et al., 2010). Finally, in the CTIC survey, the perception that cover crops are costly was the principal barrier to adopting cover crops in the survey, said by 34% of respondents to always limit adoption, 54% to somewhat limit adoption, and 12% not to limit adoption. On a similar management-oriented note, concerns that cover crops are tough to terminate was said by 29% of respondents always to limit adoption, while 52% said they somewhat limit adoption and 19% said such concerns do not limit adoption (CTIC, 2014).

In order to increase the cover crop use in the United States, two major programs have been developed by the United States Department of Agriculture (USDA). First, the Environmental Quality Incentives Program (EQIP) provides financial and technical assistance to producers for implementing conservation practices or activities like conservation planning that address natural resource concerns on their land. In 2015, the payment rate for winter-kill cover crop species was $45 per acre with a maximum payment cap of $22,500 per year (NRCS, 2015). The Conservation Stewardship Program (CSP) helps producers maintain and improve their existing conservation systems. CSP provides two types of payments through five-year contracts: annual payments for installing new conservation activities and maintaining existing practices and supplemental payments for adopting a resource-conserving crop rotation. Maximum annual payments can reach $40,000, and the CSP can be applied to continuous cover crops and cover crop mixtures (USDA, 2014b). Thus, with the availability of these two cost-share assistance programs, cover crop use is likely to increase in the future.

Cover crops have been proven to provide several advantages for the various past field experiments or studies that used meta-analytic methods. However, these benefits seem to not be enough of an incentive to drive farmers into adopting cover crops. Their main constraint is that the additional cost and management in growing cover crops seems to be higher than the benefits. In this next section, we will review the past studies on the economics of cover crops.

2.7 Review of Previous Studies on the Economics of Cover Crops

The results of quantifying benefits and costs of cover crops can be different across studies. In fact, many factors can affect the results: choice of cover crop species, choice of benefits to include, data available, and choice of costs to quantify. Indeed, as we saw in the previous sections, there are several ways of planting and killing cover crops. Therefore, behind each study, many assumptions have been made.

Frye *et al.* (1985) evaluated the net returns of several winter cover crops that are a source of nitrogen for no-till corn from 1977 through 1981. The experiment was to analyze the effects of three levels of N fertilizer (0, 50, and 100 kg per hectare of N as ammonium nitrate) on yields in a Kentucky experiment station farm. One of the goals of the study was to compare the effects of hairy vetch, big flower vetch, crimson clover, and rye on yields with corn residue cover as the control. A $14 per hectare cost for aerial seeding of each cover crop was assumed. Annual variable costs per hectare for establishing cover crops were $63 for rye, $66 for crimson clover, $111 for big flower vetch, and $82 for hairy vetch. At the zero fertilizer level, the average corn yield results for corn residue have only been 3.77 Mg/ha, 4.04 for rye, 4.22 for big flower vetch, 4.43 for crimson clover and 6.42 for hairy vetch. According to the authors, these results suggest that hairy vetch increased soil productivity over time more than the other cover crops. The results summarized in table 2.2 suggest that net returns increase in each treatment case as the fertilizer application rate increases. In all cases, the results showed that hairy vetch is by far the most profitable cover crop. For example, the average net return for a fertilizer level of 100 kg per hectare was $512 per hectare. For the other cover crops, depending on the level of N fertilizer applied, their average net return is either slightly above or worse than the average net return of corn residue cover (Frye et al., 1985).

Table 2.2: Returns Above Direct Expenses for No-Till Corn with Winter Cover Treatments and Fertilizer N Rates

Cover crop		Net Returns ($/ha) by Fertilizer N Level (kg/ha)		
		0	50	100
Average (1977-1981)	Corn residue cover (control)	97	219	355
	Rye	62	208	373
	Crimson clover	101	195	349
	Big flower vetch	33	258	217
	Hairy vetch	296	310	512

Source : Frye et al. (1985)

Snapp *et al.* (2005) provided a review of the benefits and costs of cover crops. Benefits were divided into benefits external to the farm, which include reduced nitrate leaching and reduced soil erosion, and benefits internal to the farm. Some of the internal benefits include a cash crop yield increase, better yield stability and reducing input costs such as fertilizer, herbicides and pesticides. Internal costs of cover crops take three forms: direct, indirect, and opportunity costs. Direct costs are the costs of establishment, which can be ten times higher for legume cover crops than for grasses. Indirect costs include cover crop management problems or hold up the establishment of the succeeding cash crop. Opportunity cost is the income from planting a cash crop instead of a cover crop.

The authors claim that the opportunity cost may be the biggest cost of cover crops due to cash crop yield losses incurred from delayed planting, competition, or substitution by cover crops. For the external costs, the authors mention a few studies where the N provided by a cover crop is not well assimilated by the subsequent cash crop that would lead to an increase in nitrate leaching which can affect the environment adversely.

Morton *et al.* (2006) assessed the economic impact of different amounts of biomass associated with growing high residue cover crops in a corn-cotton rotation. In their study, they calculated the level of biomass needed that would provide a gain in revenue from the cash crops that is greater than or equal to the cost of growing cover crops. The experiment was conducted in Alabama and Florida, where they analyzed the effect of planting and termination dates of rye and crimson clover on cover crop biomass, cash crop yields, and weed suppression. They assumed that producers are profit maximizers and risk-neutral. Findings suggest that the minimum amount of rye cover crop biomass needed to make it economically viable to plant was 5072 pounds with a cost of planting and managing rye of $55.14 per acre. For crimson clover, this level was 4,968 pounds of biomass with a cost of planting and managing crimson clover of $33.54 per acre. In Alabama and Florida, the authors claimed that rye has to be planted approximately nine to ten weeks after the corn harvest and terminated four weeks before cotton is planted in order to achieve these profitable levels of biomass. Crimson clover needs to be planted approximately four weeks after the cotton is harvested, and its termination dates were found to be insignificant, so any of the termination dates would suffice to reach profitable levels of biomass (Morton et al., 2006).

Pratt (2012) did a benefit cost analysis of several cover crops: annual ryegrass, cereal rye, crimson clover, hairy vetch, oats, oilseed radish, and two mixes (annual ryegrass with oilseed radish and annual ryegrass with crimson clover). The four agronomic benefits of cover crops quantified were (1) increased soil organic matter, (2) added nutrient content, (3) reduced erosion, and (4) reduced compaction. Reduced erosion included two values: on-site value of soil erosion (private) and off-site value of soil erosion (society). The costs of cover crops quantified included aerial seeding establishment cost, chemical termination cost, and unexpected costs. Unexpected costs accounted for an unexpected negative event such as needing more than one pass of cover crop termination. The results of the analysis suggested that from a private perspective (on-site value of soil erosion), all cover crops except hairy vetch and oilseed radish yielded a net benefit. From a social perspective, all cover crops yielded net benefits except oilseed radish (Pratt, 2012).

Gabriel *et al.* (2013) conducted field studies in Spain to assess the economic and environmental analysis on the adoption of cover crops grown between corn seasons. The cover crops considered were barley, rapeseed, and vetch. The baseline scenario in the economic analysis was the fallow followed by a corn crop. The economic scenarios considered in the analysis were (1) leaving the cover crop residues in the soil and reducing fertilization, (2) leaving the cover crop residues in the soil and not reducing fertilization, or (3) selling the cover crop biomass for animal feeding and not reducing fertilization. When left on the field, the cost of cover crops assumed was 67.91 € per hectare for barley, 72.70 € per hectare for rapeseed, and 71.65 € per hectare for vetch. When cover crop biomass were sold as animal feed, the cover crop cost was reduced to 27.91 € per hectare for barley, 32.70 € per hectare for rapeseed, and 31.63 € per hectare for vetch. The results showed that when cover crops are sold as forage instead of keeping them in the soil, greater profit and less leaching of nitrates are achieved than in the baseline scenario. While the fertilizer saving will be lower if cover crops are sold than if they're kept in the soil, the revenue obtained from the sale of the cover crops compensates for the reduced fertilizer savings.

Overall, the existing research on the economics of cover crops provides interesting results on the profitability of cover crops. However, the results are only valid under the research conditions and assumptions made. In the next section, we will review the previous research on the different farming practices. These practices include mainly tillage systems comparisons. These studies will help us better identify the aspects to take into account when comparing the yields between cover crop and non-cover crop fields.

2.8 Comparison of Management Practices

Quantifying differences in management practices in agriculture is not an easy task because every farm is different. In this section, we are interested in the methodology of past research when comparing two or more agricultural practices.

For several years, great effort has been devoted to the study of differences between tillage systems. Parsch et al. (2001) aimed to compare yields and estimate the profitability of six cropping systems, each grown under conservation and conventional tillage on clayey soils in a field experiment in Arkansas. The cropping systems included continuous soybean, continuous grain sorghum, soybean-grain sorghum rotation, soybean-corn rotation, continuous cotton, and continuous soybean but non-irrigated. The economic analysis was conducted by assembling annual enterprise budgets on field data collected over the 6-year period of the study. The annual enterprise budget projected costs of production, gross revenue, and net returns for a specified management alternative. The results suggested that conventional tillage had a higher average net return than conservation tillage for all cropping systems, with the exception of continuous cotton (Parsch *et al.*, 2001).

Ribera *et al.* (2004) criticized using only average net returns to decide if an alternative system is best. These authors argued that variation in net income needed to be considered when comparing production systems. In their research, their objective was to compare the economics of conventional tillage with no-tillage in South Texas. The experiment included wheat-soybean rotation, sorghum-wheat-soybean rotation, continuous sorghum, continuous wheat, and continuous soybean under both tillage systems. Yields and inputs such as seed and chemicals used were collected from a field experiment from 1984 to 2001. Other production costs were taken from the literature, and a 30% reduction from the conservation tillage budget on fuel, lubricants, labor, machinery, and depreciation was assumed in the no-tillage budget. A Monte Carlo simulation model was used to estimate empirically net income per hectare for different tillage systems under risk. Also, certainty equivalents were used to predict rankings or preferences of conventional tillage versus no-tillage for decision makers having different levels of risk preference, summarized in table 2.3. In this table, a positive value indicates the dollar per hectare benefit of no-till over conventional till. A negative value indicates the dollar per hectare benefit of conventional till over no-till. Overall, no-till is preferred over conventional till, with a few exceptions in continuous sorghum and continuous soybeans (Ribera et al., 2004).

Table 2.3: Risk Premiums between No-Tillage and Conventional Tillage Systems

Rotation	Risk loving	Risk neutral $/ha	Risk averse
Sorghum–wheat–soybean	51.88	8.45	17.79
Wheat–soybean	20.76	18.38	32.57
Continuous sorghum	-88.78	-3.88	12.60
Continuous wheat	51.77	33.88	34.25
Continuous soybean	27.75	-47.05	27.82

Source : Ribera et al. (2004)

Another study attempted to quantify the benefits and costs of the conservation tillage system. The analysis considered five crops: corn, soybeans, winter wheat, spring wheat, and durum wheat. The data used in the analysis comes from different literature sources. The analysis did not give conclusive evidence that conservation tillage leads to higher yields. In addition, he argued that costs of inputs are dependent on site-specific factors such as soil characteristics or the local weather, so general inferences about production costs are not possible (Uri, 2000).

To sum up, when comparing management practices, several factors need to be taken into account. Soil types, weather, and many other factors can affect your yield other than your treatment. The use of field experiment seems to be the most appropriate way to quantify the economics of a certain farming practice, but those results cannot be broadly valid.

2.9 Conclusion

Despite their numerous suggested agronomic benefits, cover crops have not been widely adopted in the Midwest. The main reason is that farmers perceive the costs to be greater than the benefits. The economics of cover crops will probably vary in each situation, and while several attempts have been made to assess the economic value of cover crops, there exist gaps in the research. This study aims to help fill these gaps and provide a framework for data collection and analysis that can be used to quantify the benefit and costs of cover crops.

CHAPTER 3. DATA AND METHODS

This chapter describes the data and methods used in an attempt to quantify the benefits and costs of cover crops. The methodology includes the data overview and description followed by the recruitment of participants. This chapter also describes how the data were modified and organized. Our original objective was to get enough useful data to be able to do a valid statistical analysis of differences in cover crop and non-cover crop fields. As was explained earlier, we were not sure if we would be able to get sufficient fields to do the complete quantitative analysis. Thus, the fallback position is that the data collection exercise would be used to inform how to design a larger survey in the future. The framework methodology and description are included in the next chapter.

3.1 Data Overview and Description

The first step in this research was to assess the data needs and build the data framework. This section will provide an overview of the data procedures and a detailed description of the data collected.

3.1.1 Overview

An Excel spreadsheet has been created to collect the variables of interest for this study. The relevancy of the data was evaluated by Dr. Eileen Kladivko, Professor in the Agronomy department of Purdue University. This step was essential since it helped us conceive if the data that we needed was available in the real world, if it can be collected, and if we are missing any variable that is important for our study. A guide to the data structure was created to help farmers fill in the spreadsheet (Appendix A). After building the first draft, we conducted a pilot test to find out if our survey and data guide form would work in the “real world” by trying it out on one farmer. The data spreadsheet was divided into three categories: the first was general information, the second was the field data, and the third part included qualitative questions. Each sheet in the spreadsheet represents one field of data. For each field, data related to the cash crops, cover crops and other information are collected. The data spreadsheet was sent to all farmers, including the ones that don't use cover crops. The next sections summarize the data collected.

3.1.2 Data Description

The section in the data description follows the section in the Excel spreadsheet previously described: general information, field data and qualitative questions. For each section, we explain the data that were collected.

3.1.2.1 General Information

In this section, the farm was given a farm code to keep the farm data confidential. In another spreadsheet, the farm code was associated with the contact information of the farmer. The number of acres farmed was also requested in this section for description purposes.

3.1.2.2 Field Data

Originally, the spreadsheet included seven fields, but participants were able to copy and paste the field sheet if they wanted to provide more fields. So it was up to the farmer how many fields s/he wanted to provide. The field data was divided into three categories: information about the cash crops, information about the cover crops and other information. Each section is described below.

3.1.2.2.1 Cash Crops

The first section of the cash crop information included field information described in table 3.1. We assumed that these characteristics are time invariant.

Table 3.1: Field Information Data

Variable name	**Description and Units**
Field size	Acres
Dominant soil type	Soil series name or Soil series abbreviation
Slope class/ Percent slope	The slope class are A, B, C, D, E, F and G or the percent slope of the field

Next, we requested information on the cash crop and other field characteristics. To evaluate the long term effect of cover crops, we created our tables by including a 10 year period, from 2004 to 2013. However, it was up to the participants how many years of data they wanted to provide. The relevant crop information collected over several years is described in table 3.2.

Table 3.2: Crop Information Data

Variable name	**Description and Units**
Crop name	Crop planted in the field
Yield	In bushels per acre
Seeding rate	In seeds per acre
Seed biotech traits	If GE crops (Bt, RR..) or if not GE crops
Additional seed treatment	If seed treated, farmer specified the fungicide or insecticide used
Tillage regime	Tillage practices in the field each year
Drainage system	If any, type of drainage system used

*GE: Genetically Engineered

After gathering data on the field practices and cash crops, we collected data on the chemical inputs applied in the fields for each year. The inputs include fertilizers, herbicides, insecticides and fungicides. The next section describes the data that were collected for these inputs.

3.1.2.2.2 Chemical Used

For the fertilizers, a list of common products was arranged to facilitate data collection. For each year, farmers had to select the product they used on that specific field and its application rate. The units for the application rates were not specified for the reason that it depends on the state of matter of the fertilizer (liquid or solid). The farmer could include the units while filling the data spreadsheet. The fertilizer products listed in the spreadsheet were:

- Anhydrous ammonia
- Nitrogen solutions (28% to 32%)
- Urea 44-46% nitrogen
- Ammonium nitrate

- Sulfate of ammonium
- Super-phosphate 20% phosphate
- Super-phosphate 44-46% phosphate
- Di-ammonium phosphate (18-46-0)
- Mono-ammonium phosphate (11-(51-55)-0)
- Potassium chloride 60% potassium
- NPK formulas
- Sulfur
- Micronutrients
- Others

NPK stands for nitrogen, phosphorous, and potassium. The formulas are a specific blend of N, P and K that are not commonly used. Therefore, the table allows participants to mention which formula they used with its application rate. Also, a category called “other” allows the farmer to enter a fertilizer that was not included in the list. For example, hog or swine manure can be listed in this category. Furthermore, we requested participants to indicate if the application rate they provide is the amount of product or the amount of nutrient (especially for the nitrogen application). This specification request was added after realizing that some application rates were in pounds of nitrogen per acre, instead of pounds of product per acre.

For herbicides, we collected the name of the product they used with the application rate for each year. The product name can be the commercial name or the name of the active ingredient of the herbicide. Also, we asked why it was applied: if it was a standard herbicide application or if it was for terminating the cover crops as a first pass or as a second pass. For each product that was used to terminate cover crops, the time and cost of termination was collected. The cost of termination includes the cost of product and the cost of spraying. Table 3.3 summarizes how data was collected with an example for 2013.

Table 3.3: Example of Data Collected for Herbicides in 2013

Product name	App rate	Reason of application: Standard	CC: 1st pass	CC: 2nd pass	Termination cover crops time	Cost termination ($/ac.)
RoundUp	1 qt./ac	X				
Atrazine	1 pint/ac	X				
RoundUp	1 qt./ac		X		04/20/2013	$13.50
Clethodium	8 oz./ac.		X			

It should be noted that if a farmer does not plant cover crops, the last four columns in this section are left blank. Finally, data on insecticide or fungicide products and their application rate was collected for each year.

After collecting data on the fertilizers and pesticides, information about cover crops was gathered. This section was only relevant to the farmers that planted cover crops in the considered field. Therefore, if a farmer did not plant any cover crops in the considered field, this section was left blank and they could move on to the next section.

3.1.2.2.3 Cover Crops

For cover crop establishment, farmers were asked to enter the method they used to plant cover crops and when they planted it. The cash crop harvest time was only requested if the method of establishment was aerial seeding. Also, we requested the name of the cover crop planted, the seeding rate and the cost of establishment. The cost of establishment included the cost of the seed (in dollars per pound) and the cost of planting depending on the method they used. Most farmers used cover crop mixes so the table allows farmers to list several crops if needed. An example for 2013 is shown in table 3.4.

Table 3.4: Example of Data Collected on the Establishment of Cover Crop for 2013

2013		
Method	Aerial Seeding	
Time	09/05/2013	
Cash crop harvest time		10/03/2013
Crop name	Seeding rate	Cost ($/ac.)
Cereal Rye	50 lbs./ac.	$45/ac.

Additionally, farmers were asked to rate the quality of their cover crop establishment for each year. The rating included: poor, below average, average, above average and excellent.

Finally, if the cover crops were not terminated by using herbicides, a section was added to the spreadsheet where the participants were able to indicate the method they used, the time of termination and the cost of termination in dollars per acre.

3.1.2.2.4 Other Information

The last part of each field sheet in the spreadsheet was called "other information". In this section, we asked farmers to provide any type of measurement that they have on their farm for each of these items:

- Soil organic matter
- Soil moisture
- Soil erosion
- Soil compaction

Soil organic matter is the most available measurement since farmers commonly get their soils tested every other year. However, we were aware that quantitative data about the last three items is not common unless the farmer specifically use some method to measure them. Hence, the information requested in this section was optional.

To sum up, for each field, we collected data over several years on the cash crops, the field practices, the fertilizers and pesticides, the cover crops and other information including soil organic matter. The next section describes the qualitative questions asked at the end of the field data collection. This section was included in the last sheet of the spreadsheet.

3.1.2.3 Qualitative Questions

This final section includes a few qualitative questions that help us understand the perception of each farmer about cover crops. If the farmer plants cover crops in his farm, seven open-ended questions were asked and listed below:

1. When did you start to consistently plant cover crops in your farm?
2. Why did you choose to plant cover crops?
3. What were the criteria you used to select which cover crops to use?
4. What do you see as the major benefits of cover crops?

5. What do you see as the major disadvantages or challenges in using cover crops?
6. What issues have you had with planting cover crops?
7. Have you received any cost share assistance or incentive payments in the past to plant cover crops?

In the case of a non-cover crop farmer, we were only interested in the reason why they don't plant cover crops. The next section will describe how we have recruited farmers for this study.

3.2 Selection of Participants

Farmer contact information was obtained from different sources. We started with a list of farmers from Indiana provided by the Conservation Cropping Systems Initiative (CCSI). Then another list of farmers in the Midwest was provided by the Conservation Technology and Information Center (CTIC). In fact, the original plan was that CTIC would provide a large number of farmer participants. Farmer recruitment in that project was delayed, and we ended up not getting as many farms as hoped. In a few conferences, crop advisors also offered help in recruiting farmers by providing a list of farmers who might be interested in the study. Finally, we asked the Purdue Extension Educators in a few Indiana counties to help us in recruiting more farmers for the study. Once the contact information was obtained, participants were contacted either by email or by phone. During the first contact, participants were explained the aims of the study, the procedures, their individual rights and the confidentiality clauses. If they were interested in participating in the study, the Excel spreadsheet with the data guide was sent to them by email or by mail. Also, if they were located in Indiana, we offered to meet with them wherever it is convenient for them (farm house or office). The face to face meetings lasted from two to four hours, depending on the number of fields of data a farmer wanted to contribute. For the participants who were not located in Indiana, we communicated via email or by phone to answer questions and help gather the data. Responses were mostly received by email, but some participants preferred to print the spreadsheet and write manually on them. Then, they would either scan it and send it by email, fax it or mail it to us. Fields were included in the dataset if the data was completed for each field.

After gathering all the data, we realized that we needed to regroup a few variables into categories to be able to work with the data and compare cover crop and non-cover crop fields. The next section describes how the data were categorized or modified.

3.3 Data Organization

This section describes how we have categorized the data on the cover crop regime, the tillage systems, the soil types, soil slopes, pesticides, seed biotechnological traits, and seed treatments. Also, we will explain how we have calculated the total amount of nitrogen only for corn observations. One observation represents one year of data within one field. For example, if the farmer provided six years of data from 2008 to 2013, then there are six observations in that field.

- Cover Crop Regime

From the data collected, we know if the field had cover crops or never had cover crops on it. Depending on how many years of data were provided, some fields did not have cover crops for the whole time period. For example, if a farmer started planting cover crops in the fall of 2011, yields for 2011, 2010 and 2009 were not influenced by cover crops. Therefore, we categorized an observation as "with cover crops" only if cover crops were planted before the cash crop growing season.

- Tillage Systems

From the raw data, there were five categories of tillage systems: conventional tillage, reduced tillage, vertical tillage, no tillage, and strip tillage. It is important to note that the tillage system names were given by the farmer without defining them. According to the U.S. Department of Agriculture, there are two major types of tillage: conservation tillage and conventional tillage (Rust & Williams, 2010). Conservation tillage includes reduced tillage, strip tillage, and no-till. We assumed that vertical tillage is also part of conservation tillage practices. Therefore, we classified the tillage systems into three categories: Conventional Tillage (CT), No-Till (NT), and Other Conservation Tillage (OCT), with OCT including reduced tillage, vertical tillage and strip tillage.

- Soil Type

When farmers were asked to provide their dominant soil type for a field, the name provided was one of a soil series. According to the NRCS, there are six categories in the U.S. soil taxonomy. In order of decreasing rank and increasing numbers of components and classes, the categories are order, suborder, great group, subgroup, family, and series (NRCS, 1999). The data collected revealed a total of 37 different soil series. This number was too big to include in our analysis. Soil series information was translated into the soil order of the U.S. Soil Taxonomy using the USDA-NRCS Soil Survey Division's Official Soil Series Descriptions on the Internet (available at: https://soilseries.sc.egov.usda.gov/osdnamequery.asp). For example, when searching for the soil series "Drummer", the result presented the taxonomy class for the soil series which is in this case "Fine-silty, mixed, superactive, mesic Typic Endoaquolls". From this description, the soil order was found as an abbreviation in the last syllable of the last word. In our example the "olls" at the end stands for mollisols, one of the 12 soil orders existing in the U.S. soil taxonomy. Table 3.5 shows some examples of soil series collected from farmers and their respective soil orders.

Table 3.5: Examples of Soil Series and their Respective Soil Orders

Soil series	Soil Orders
Drummer	Mollisol
Xenia	Alfisol
Latty	Inceptisol
Castle	Vertisol
Birds	Entisol
Fox	Alfisol

This way, we were able to regroup 37 soil series into five categories of soil orders: alfisol (alf), entisol (ent), vertisol (ert), inceptisol (ept) and mollisol (oll).

- Slope

For each field, farmers provided information on the field slope or a slope range with a large amount of different slope classes. The NRCS provides a recommended slope class with different slope gradients limits. For example "nearly level" is defined with a slope class from 0 to 3% and “gently sloping” is defined with a slope class from 1 to 8% (Soil Survey Division Staff, 1993). Based on this classification, we have regrouped the slopes into four categories: 0 to 2%, 2 to 6%, 6 to 12%, and 12 to 20%.

- Pesticides

For herbicide, insecticide and fungicide sections, farmers provided the product brand name or the active ingredient name. An active ingredient is the ingredient in a pesticide that is biologically active. Therefore, we have looked for the active ingredients in each product brand name provided in order to classify them by active ingredient. Tables B.1, B.2, and B.3 in Appendix B show the names of the active ingredients and their associated brands of herbicides, insecticides, and fungicides. Moreover, the application rate units provided depended on how the farmer recorded them. Most of them are in fluid ounces per acre, but some are in quarts per acre, pints per acre or gallons per acre. Therefore, we have converted the application rates in pints, quarts, and gallons into fluid ounces by using the U.S. customary units for conversion. One pint corresponds to 16 fluid ounces, one quart corresponds to 32 fluid ounces, and one gallon corresponds to 128 fluid ounces.

- Seed Biotechnological Traits

Fernandez-Cornejo et al. (2014) reported that genetically engineered seeds have been widely adopted by corn, soybeans, and cotton farmers in the United States. There exist a variety of genetically engineered traits, but the most common ones are insect resistance and herbicide tolerance traits. Insect resistant or Bt crops contain a gene from the bacterium *Bacillus thuringiensis* (Bt) that produces a toxic protein to certain insects, including the European corn borer, the corn rootworm, and the corn earworm. Corn and cotton are two Bt crops that are available in the United States. Herbicide tolerant crops have traits that allow them to tolerate herbicides such as glyphosate or glufosinate. A well-known herbicide brand that contains glyphosate is Roundup® from Monsanto and Roundup Ready® is the glyphosate tolerant traits in the seed. Along similar lines, a popular herbicide brand that contains glufosinate is Liberty®. And the glufosinate tolerant trait is called LibertyLink®, developed by Bayer Crop Science. Stacked traits are a combination of two or more genes of interest in a single plant. Farmers responses to the question on the seed biotechnological traits included : “RR” for the Roundup Ready® trait, “LL” for the LibertyLink® trait, “double stacked”, “triple stacked” or the variety name such as “P 32B16”. Therefore, we classified the seed into three categories: (1) Herbicide tolerant that regroup the Roundup Ready® and LibertyLink® traits, (2) Stacked traits for double and triple stacked seeds, and (3) No traits.

- Seed Treatment

Several seed companies offer seed treatment when the farmer buys the seed. Seed treatments cover the seed and can protect it from pest attacks and diseases. Therefore, the treatments include a fungicide product, an insecticide or a combination of both. Farmers response’s included the treatment brand name or if it is an insecticide or a fungicide. We have classified the responses into four categories: (1) insecticide, (2) fungicide, (3) combination of insecticide and fungicide, and (4) no treatment.

- Total Amount of Nitrogen

As described in the data section, we collected information on fertilizer used and their application rate for each year and in each field. Therefore, for each year when corn was planted, we calculated the total amount of nitrogen applied in pounds per acre. In fact, each product contains a specific amount of nitrogen. Table 3.6 summarizes the percentage of nitrogen contained in each product.

Table 3.6:Nitrogen Composition in Fertilizers

Product name	**Percentage of Nitrogen**
Anhydrous ammonia	82 %
Nitrogen solutions (28% to 32%)	28% to 32%
Urea 44-46% nitrogen	44 or 46%
Ammonium nitrate	34%
Sulfate of ammonium	21%
Di-ammonium phosphate (18-46-0)	18%
Mono-ammonium phosphate (11-(51-55)-0)	11%

In the NPK formulas, the first number is the percentage of nitrogen included in the blend. Some farmers used hog, turkey or swine manure to fertilize their fields. In order to get the amount of N in the manure, we requested that farmers send us the manure analysis. Manure is analyzed for total nitrogen, total phosphorus, total potassium and moisture content. Therefore, we were able to calculate the amount of nitrogen included in the manure. The next section will describe how we have quantified the costs for a selection of cover crops that will be described in the next chapter.

3.4 Cover Crop Cost Quantification

As described in the section 3.1.2, cover crop establishment cost included the cost of planting and the cost of the seed. The termination cost included the cost of spraying and the cost of the herbicide used. The cost assessment is done in 2013 dollars, so all costs are converted according to the Producer Price Index (PPI) for all commodities (FRED, 2015). The PPI measures average changes in commodity prices, including the price of seed and the price of herbicide product, which make it suitable for this assessment. For example, a farmer provided a cost of termination of annual ryegrass in 2010 of $14.25 per acre. We have converted this cost by multiplying it with the PPI of 2010, which is 0.908. Hence, the real value of the cost is $15.69 per acre with 2013 as the base year. We have then calculated the minimum, maximum and the average cost for each cover crop planted in fields with a corn-soybean rotation.

3.5 Dataset Conception

A dataset was structured in order to be used in a multiple regression analysis to quantify the yield differences between cover crop fields and non-cover crop fields. Two datasets were created, one for the corn observations and one for the soybeans observations. Each dataset included the farm number, the field number, the year of the observation, the crop name and its yield, the cover crop regime, the tillage system, the slope class and the soil order. Only for the corn dataset, we have included the total amount of nitrogen.

We will see in the next chapter that the multiple regression analysis did not provide conclusive results. There was simply too much variability in the farms and management practices, and the number of farms and fields was much too small to do any reliable quantitative analysis. Therefore, we have designed a research framework that could be used for future research on the benefits and costs of cover crops.

CHAPTER 4. RESULTS AND FRAMEWORK FOR FUTURE RESEARCH

Results reported in this chapter correspond to a description of the data collected. Results begin with an overview of the data, including the number of farmers interviewed, the location, and the number of fields. Next, we will describe specific characteristics of the data collected related to the fields, the cash crops, the chemical inputs and the cover crops. As the description will show, we did not get enough data to do the quantitative analysis, so the real contribution of this research is to aid in improving future research projects in this area. At the end of the chapter, we will propose a design for future studies to better quantify the benefits and costs of cover crops. This design includes a description of the farm selection process, the data needs, the number of recruits, and other considerations to take into account. It was developed based on what we learned in this research project.

4.1 Overview of the Data

The data collection lasted eight months, from June 2014 to February 2015. During that period, a total of 56 farmers were contacted, but only 21 farmers provided complete data on their fields, which corresponds to a response rate of 37.5%. A total of 82 fields of data was collected, including 52 fields with cover crops and 30 fields without cover crops. The mean number of fields collected by farm is four, with a minimum of one field and a maximum of 14 fields per farm. Of the 82 fields, 56 were in Indiana, seven in Minnesota, five in South Dakota, four in Illinois, four in Iowa, four in Ohio and two in Michigan. Figure 4.1 illustrates the share of fields by state.

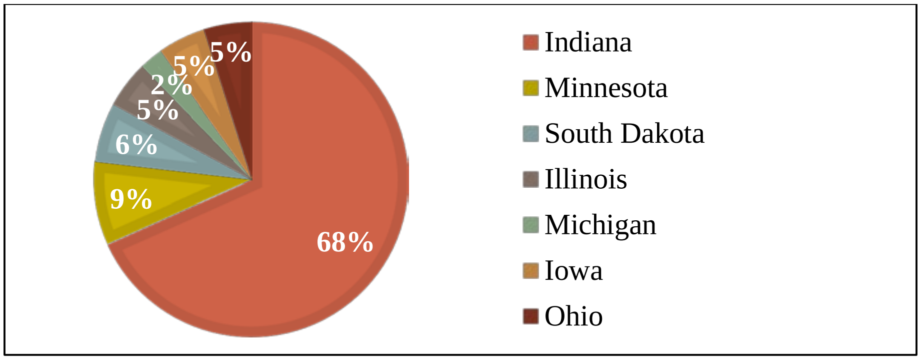


Figure 4.1: Composition of Fields Included in the Study

The fields in Indiana came from 11 counties. As can be seen in table 4.1, we have classified the fields into three regions of Indiana. The northern region included Wabash, Benton and Adams counties. The central region included Vermillion, Fountain, Tippecanoe and Hancock counties. Finally, the southern region included Knox, Decatur, Dubois and Vanderburgh counties. The fields were quite evenly distributed among the northern, central and southern regions of Indiana. However, the northern region and the southern region account for almost of 80% of the cover crop fields collected.

Table 4.1: Number of Fields of Data Collected by Region in Indiana

Region of Indiana	**Cover crop fields**	**Non-cover crop fields**	**Total fields**
Northern region	15	3	18
Central region	8	8	16
Southern Region	15	7	22
Total	38	18	56

In regard to the number of years provided, the mean years of data provided is 5 years, from 2009 to 2013, with a minimum of 2 years (2012-2013) and a maximum of 10 years (2004-2013).

In the next section, we will describe more in detail the data that we have collected. The description will include the field's characteristics, the cash crops, the chemical inputs and finally cover crops.

4.2 Data Description

4.2.1 Field Characteristics

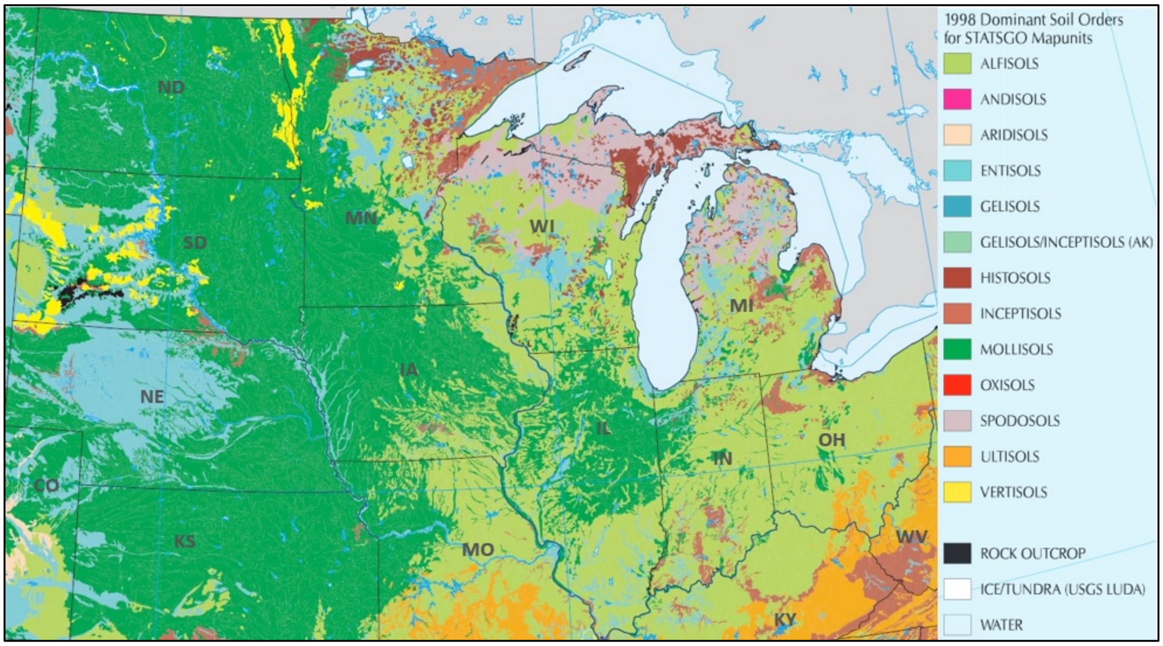
In this section, we will provide a description of the soil orders, soil slope, tillage regime and soil drainage systems of the fields collected.

As explained in the previous chapter, soil series were categorized into their respective soil orders. The soil order is the highest rank category in the U.S. Soil Taxonomy. Table 4.2 describes the number of fields in each soil order.

Table 4.2: Number of Fields per Soil Order

Soil order	**Cover crop fields**	**Non-cover crop fields**	**Total fields**
Alfisol	30	13	43
Mollisol	20	10	30
Vertisol	0	3	3
Inceptisol	2	3	5
Entisol	0	1	1
Total	52	30	82

Almost 90% of the fields were categorized into the Alfisol and Mollisol soil orders. This number makes sense because most of the soil in the area of the study are Alfisol and Mollisol (see figure 4.2). The one field that is entisol came from the soil series Birds located in southern Indiana. Inceptisol fields came mostly from the southern counties of Indiana and from Fulton County in Ohio, which is located in the North West region of Ohio. Finally, the Vertisol fields came from Vermillion County, which is located in west central Indiana.



Source : Adapted from NRCS (1998a)

Figure 4.2: Soil Orders in the Area of Study

Table 4.3 presents the number of fields per slope class category. A majority of the fields had a nearly level slope ranging from 0 to 2%. The one field with a slope of 12 to 20 % along with three other fields with slopes 6 to 12% were located in Wabasha County in Minnesota (MN), which is in the southeast region of the state. Other fields with 6 to 12% were from Dubois and Decatur counties, located in the southern region of Indiana. Most of the sloping fields (above 6%) were under cover crops which could convey that cover crops are planted to control higher erosion rated on the sloping fields.

Table 4.3: Number of Fields per Slope Class

Slope class	**Cover crop fields**	**Non-cover crop fields**	**Total fields**
0-2%	33	21	54
2-6%	8	6	14
6-12%	10	3	13
12-20%	1	0	1
Total	52	30	82

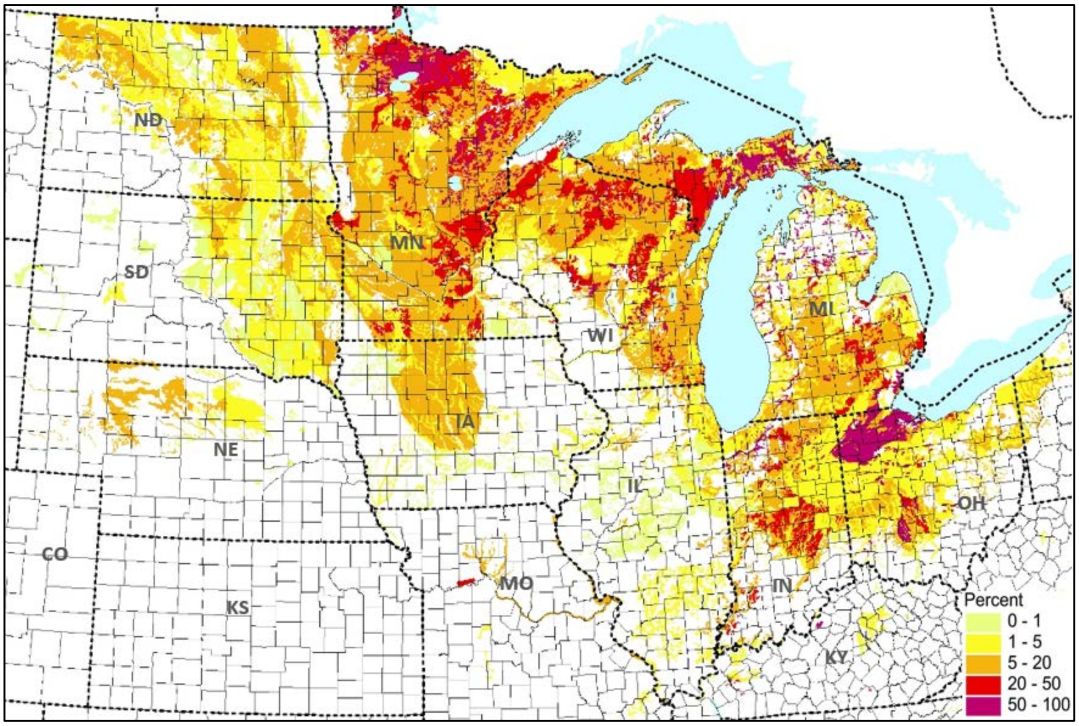
In regard to the tillage systems, almost 64% of the fields were in No-till (table 4.4). However, a third of the fields had some alternation between NT and either CT or OCT. Some of them included three years of NT with one year of CT, or two to three years of NT and one year of OCT. It should be noted the data does not include fields under strict conventional tillage. Under no-till systems, we can see that a majority of the fields were with cover crops. Most of the farmers interviewed mentioned that they started by adopting conservation tillage practices before introducing cover crops in their farming systems. For the fields collected in Indiana, 92% of corn observations and 95% of soybean observations were under no-till. In 2013, 21% of corn acres were under no-till, and 55% of the soybeans were under no-till (Harmon, 2015). These numbers reveal that our data is not representative.

Table 4.4: Number of Fields per Tillage System and Cover Crop Regime

Tillage system	**Cover crop fields**	**Non cover crop fields**	**Total fields**
NT	39	13	52
OCT	5	0	5
Alternating NT-OCT	5	12	17
Alternating NT-CT	3	5	8
Total	52	30	82

In regard to the fields’ drainage systems, 48 fields had a subsurface drainage system that included pattern tile or tile. Surface drainage was reported in three fields that have Water And Sediment Control Basin (WASCOB). These basins are used to reduce gully erosion, trap sediment and reduce and manage downstream runoff. Two fields were reported to have a subsurface tile and a surface WASCOB. The U.S. Soil Taxonomy suggests that there are seven classes of soil drainage, going from very poorly drained soils to excessively drained soil. The figure 4.3 shows the percentage of very poorly drained soils in the area of the study. As you can see on the map, a good part of Indiana soil is very poorly drained. This is compatible with our field data in Indiana since 70% of the fields had a subsurface drainage system. Similarly, three fields located in Williams

County in Ohio, which is located in the northeast of Ohio, had a subsurface drainage system.



Source: Adapted from Schmidt (2008)

Figure 4.3:Percentage of Very Poorly Drained Soils in the Area of Study

To sum up, the field characteristics for soil orders, soil slopes, and drainage systems are consistent with reality. However, the prominence of no-tillage in the fields collected for this study is not representative of the tillage systems adopted by a majority of farmers. In the next section, we will focus on the cash crop characteristics by describing the crop rotations, the seed biotechnological traits and the seed treatments in the fields collected for this study.

4.2.2 Cash Crops

One characteristic of the data collected is the multiplicity in the types of rotations reported in table 4.5. The crops used by farmers in the fields are corn, soybeans, winter wheat, spring wheat, and white corn. Winter wheat or oats mean that depending on the year, the farmer chose to plant either winter wheat or oats, without following a distinct order. The same logic applies to spring wheat or winter wheat. Around 57% of the fields were in a corn-soybean rotation, followed by 17% in a winter wheat or oats-corn-soybeans rotation, and the rest in various other rotations. Four fields were in a white corn-soybeans rotation. White corn is a corn hybrid that is not genetically modified to have specific traits such as insect resistance or herbicide tolerance. It is destined for the food market. Double cropping of soybeans following winter wheat is observed in four fields of the data collected. Those fields were located in Knox County, in the southern region of Indiana, where the growing season is long enough for these two crops to be grown in one season. Researchers have demonstrated that an increase in the diversity of crop species in a rotation had a significant positive effect on grain yields (Smith *et al.*, 2008). Therefore, in our case, we should be able to compare the crop yields between cover crop fields and non-cover crop fields only within the same rotation, which decreases significantly the number of fields that we can use in the analysis.

Table 4.5: Number of Fields by Type of Rotation

Rotation type	**Number of fields**
Corn- Soybeans	47
Winter Wheat or Oats-Corn-Soybeans	14
White Corn- Soybeans	4
Winter Wheat/Double Crop Soybeans-Corn-Soybeans	4
Corn-Corn-Soybeans	3
Spring or Winter Wheat-Corn-Soybeans	3
Spring Wheat-Corn-Soybeans	2
Winter Wheat-Corn-Soybeans	2
Continuous Corn	1
Corn-Corn-Corn-Corn-Soybeans	1
Corn-Soybeans-Soybeans	1
Total	82

In regard to the seed biotechnological traits, the data suggests that 51% of the corn had stacked traits, 43% had an herbicide-tolerant trait and the rest with no traits. A report from the Economic Research Service (ERS) revealed that stacked trait corn was planted on 76% of corn acres in 2014, and 13% had herbicide-tolerant traits only (Fernandez-Cornejo et al., 2014). One possible reason for this large difference in numbers is that farmers mentioned that their corn was herbicide tolerant with only one trait, but it possibly had two traits of herbicide tolerance, which would, therefore, be considered as a stacked seed. For soybeans, the data suggest that 100% of the soybeans had an herbicide tolerant trait that was mostly Roundup Ready®. This number is above but close to the estimation from ERS that 93% of soybeans had an herbicide tolerant trait in 2013. Finally spring wheat, winter wheat, and oats have been reported with no genetically engineered traits, as there are no commercially available wheat or oats that are genetically modified. According to the same ERS report, genetically modified crops lead to higher yields compared to non-genetically modified crops. Hence, we cannot include white corn yields in the analysis since they are genetically different from the majority of corn that is genetically modified.

In addition to growing crops with genetically modified traits, farmers added a fungicide or insecticide treatment on their seeds. Indeed, 49% of the genetically modified corn had a seed treatment against 42% that didn't use any seed treatment, and the rest of the observations had no answers. The main seed treatment used on genetically modified corn was insecticide for 72%, followed by a combination of fungicides and insecticides (24%) and the rest with only fungicides. For all the white corn planted, the only seed treatment used was insecticides. Seed treatment was applied to 42% of the soybeans. A majority of the seed treatments for soybeans were a combination of insecticides and fungicides (73%), followed by 16% with insecticides and the rest with fungicides. Half of the spring and winter wheat observations had a fungicide treatment. Finally, no seed treatment was reported for oats.

The seeding rate was requested for each crop. Table 4.6 provides the descriptive statistics of seeding rates for corn and soybeans in seeds per acre.

Table 4.6: Descriptive Statistics of Seeding Rates for Corn and Soybeans

	Corn		**Soybeans**	
	Cover crops	Non cover crops	Cover crops	Non cover crops
Mean	32968	32750	151407	164453
Std. dev	3324	2591	15864	19880
Min	24000	25000	130000	130000
Max	39000	36000	190000	200000

The variability in seeding rate for corn and soybeans can be related to different factors. A farmer chooses a seeding rate depending on the date of planting, if a seed treatment was incorporated, on the price of the seed and the yield that (s)he wants to reach. One farmer was planting wheat and oats as cash crops in his fields. Wheat average seeding rate was 123 pounds per acre and oats seeding rate was 90 pounds per acre.

The table 4.7 provides the descriptive statistics for corn and soybean yields by separating the observations between cover crop and non-cover crop fields. For both crops, there is a slight difference of the mean yields. The average corn yield in cover crop fields is higher by 2.5 bushels per acre compared to the average in non-cover crop fields. For soybean yields, the difference is minimal, about 1.2 bushels per acre. However, as the t-test demonstrated, these differences are not statistically significant. The minimum yields for corn and soybeans are very low because they represent the yields during the very dry 2012 growing season. The variances are very high rendering the data not usable for statistical comparison.

Table 4.7: Descriptive Statistics for Corn and Soybean Yields (bu. /ac)

	Corn		**Soybeans**	
	Cover crops	Non cover crops	Cover crops	Non cover crops
Mean	173.3	170.8	53.60	54.74
Std. dev	41	38	11.21	10.37
Min	63	74	26	25
Max	264	257	72	74

As suggested in this section, each farm is unique. Some farmers preferred to grow several crops in the rotation compared to the classic corn-soybeans rotation. The possible reasons include longer growing season or agronomic benefits of an increase in the crop biodiversity. Also, even if most farmers used genetically modified crops in their fields, some preferred to grow conventional hybrids. Almost half of the corn and soybeans grown in the fields of the study had an additional seed treatment incorporated. This shows that including a seed treatment depends on the farm, especially the insect and pathogen populations in the area, but also on the weather conditions for the specific year. Seeding rates can vary from a farm to another, depending on the goals of the farmer, but also on the price of the seed. Finally, statistics descriptive shows a difference in yields between cover crop and non-cover crop fields, but we cannot conclude that the difference is statistically significant. The next section will describe the chemical inputs used in the fields collected. The chemicals considered include fertilizers, herbicides, insecticides, and fungicides.

4.2.3 Chemical Inputs

The fertilizer data collected suggests that the major source of nitrogen for 76% of the corn planted was a nitrogen solution that contains either 28% or 32% of nitrogen. Urea 44% or 46% was the second source of nitrogen followed by sulfate of ammonium. The major source of phosphorus for corn came from di-ammonium phosphate (18-46-0) and the main source of potassium was potassium chloride (60% potassium). While commercial fertilizers are the major source of applied nutrients, animal manure also contributed nutrients for crop use. A total of four fields had turkey or swine manure applied to them, and two fields had hog manure applied on them. The table 4.8 provides the descriptive statistics output for the total nitrogen applied to each field on corn. Table 4.8 suggests the manure application generally provide more nitrogen compared to commercial fertilizer. Also, the average amount of nitrogen applied per acre on non-cover crop fields is higher than the average of the cover crop fields. The standard deviation and range between minimum and maximum are smaller for the non-cover crop fields.

Table 4.8: Descriptive Statistics for Nitrogen Application in Corn (lbs./ac)

	Commercial fertilizer		**Manure**	
	Cover crops	Non cover crops	Cover crops	Non cover crops
Mean	174.8	187.6	233.1	214.9
Std. dev	50.3	34.8	58.3	33.0
Min	111.5	122.2	150.9	178.0
Max	279.8	264.0	295.7	244.4

Almost half of the soybeans planted were reported to have no fertilizer applied. Most of the fertilizer applied was potassium. The most used product as a source of potassium was potassium chloride (60% potassium). Since soybeans are a legume crop, it doesn't need nitrogen fertilization. For oats, the only fertilizer applied was a specific blend of nitrogen, phosphorous, and potassium that would provide 10.72 pounds per acres of nitrogen. For all the spring wheat planted, nitrogen solution 28% and Urea 44% was applied. Finally, winter wheat had mostly the same NPK blend as oats and also mono-ammonium phosphate (11-(51-55)-0).

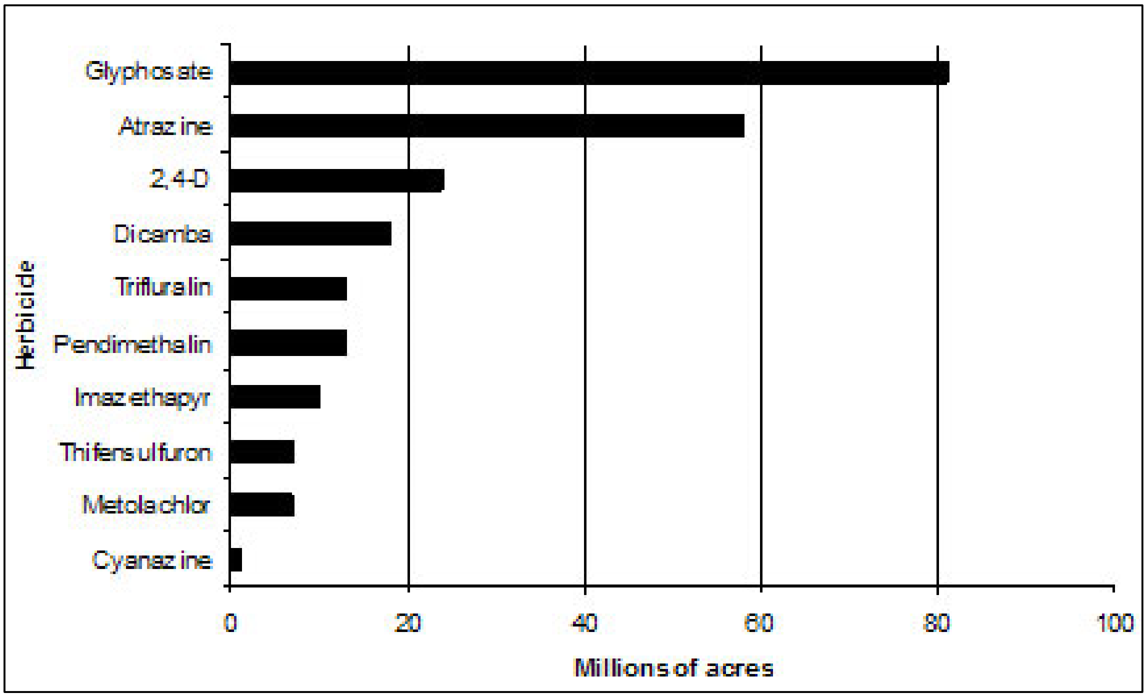
After converting each product name into its active ingredient, we ended up with 412 observations of herbicides for corn. This number is high because several herbicide products can be used in one year of corn observations. The most used active ingredient on corn was glyphosate (38%) followed by atrazine (21%) and 2,4-D (12%). The abbreviation 2,4-D stands for 2,4-Dichlorophenoxyacetic acid. For soybeans, there were 455 observations for herbicides. The most used herbicides in soybeans is glyphosate at 44%, followed by 2,4-D at 15%. Table 4.9 provides the descriptive statistics on the application rates (in ounces per acre) for the relevant active ingredients in corn and soybeans.

Table 4.9: Descriptive Statistics for Herbicides Application Rate in Corn and Soybeans (oz./ac)

	Corn			**Soybeans**	
	glyphosate	atrazine	2,4-D	glyphosate	2,4-D
Mean	26.26	35.90	13.05	31.61	12.13
Std. dev	7.93	23.54	4.82	11.63	7.03
Min	2.00	2.24	3.00	8.06	1.42
Max	48.64	96.00	17.66	67.20	32.00

For oats, observations come from the same farm where the farmer used mainly citric acid as the herbicide. The average application rate was 24 ounces per acre. The other herbicide used was 2,4-D with an average application rate of 28 ounces per acre. For the white corn, the farmer used mostly glyphosate (25%) and nicosulfuron (25%) followed by s-metolachlor (21%) and 2,4-D (17%) as its herbicides. On the four fields where spring wheat was planted, a total of 22 observations of herbicides was reported. The most used herbicide was fenoxaprop (36%) followed by MCPA (32) and glyphosate (27%) For winter wheat, MCPA was used as the main herbicide (41%) followed by 2,4-

D (21%). The data on herbicides used seems to match the estimation on the ten most used herbicides on agricultural lands illustrated by the graph in figure 4.4.



Source: Todd and Suter II (2010)

Figure 4.4: Herbicide Application on Agricultural Land in the United States in 2001

Unlike herbicides, insecticides are not applied every year on each crop. Only 37% of the corn observations in the data collected had an insecticide application and 22% for soybeans. The most used insecticides for corn were beta-cyfluthrin with 22 of the observations followed by tefluthrin with 12 observations. Both active ingredients are classified as pyrethroid, an organic compound that attack the nervous system of insects. The most used insecticides on soybeans are deltamethrin and imidacloprid. Similar to insecticides, fungicides are applied only when needed. For the corn observations, 24% had a fungicide application and 15% for soybeans. Most used fungicides for corn are azoxystrobin (37%) and pyraclostrobin (37%). On soybeans, pyraclostrobin is the most used fungicides (44%) followed by trifloxystrobin (31%).

The next section will describe the cover crop data gathered. We will first describe the cover crops and their different management. Then we will assess cover crop costs for cover crops in corn-soybean rotation fields. Finally, we will present the different perceptions of farmers about cover crops.

4.2.4 Cover Crops

4.2.4.1 Overview

The number of fields collected with cover crop data is 52. A total 17 fields had cover crops planted every year. However, some fields did not have cover crops planted systematically every year. On 17 fields, cover crops were alternating. Some of the fields showed a clear pattern where cover crops are not planted after soybeans and before corn, but mostly after the corn season. The rest of the fields had their ground covered all the time and not only with cover crops but also with other crops. As previously mentioned, four fields were in a wheat double-crop soybeans- corn- soybeans rotation. Therefore, the farmer could seed cover crop into the double crop soybeans and kill it before planting corn, and then seed it into the standing corn and kill it before planting the full season soybeans. However, after harvesting the soybeans in mid-October comes the growing season of wheat in November. Therefore, there is no time between these two crops to plant a cover crop. A similar scenario was followed for the 14 fields with a winter wheat or oats-corn-soybean rotation. Therefore, there are 18 fields where the soil is covered every year, but not necessarily with a cover crop every year.

Among the 52 cover crop fields, the total number of observations with cover crops is 154. As previously mentioned, one observation refers to one "crop-year" within one field. In our dataset, some farmers seed only one cover crop in each year, and some prefer to seed a mix of cover crops. Single cover crops represent 53% of the observations, and the cover crop mixes represent 47%. Cereal rye was the most used single cover crop (52%) followed by annual ryegrass (23%), winter wheat (12%), oats (11%) and radish. The cereal rye was mostly drilled or aerial seeded. Annual ryegrass and radish were mostly aerial seeded, or air seeded. Oats were all established with a planter and wheat was either drilled or broadcasted. The cover crop mixes were very diverse and included from two to five cover crops. The five-way mix represented 18% of the mixes and included two grasses (annual ryegrass and oats), two brassicas (radish and rapeseed or turnips) and one legume cover crop (crimson clover or hairy vetch). Like the five-way mix, the four-way mix included one or two cover crop from each of the three families. The only difference with the five-way mix is the use of peas instead of hairy vetch as a legume. The three-way mix represented 36% of the cover crop mixes and was composed of annual ryegrass, crimson clover, and radish. Finally, the two-way mix was composed of annual ryegrass and crimson clover and represented 12% of the mixes. Overall, annual ryegrass and crimson clover seems to be the cover crops that are most used in the mixes. Most of the mixes were established by using a planter (31%), followed by aerial seeding (27%), then drilling (27%) and finally air seeding (15%).

In the next section, we will assess the costs for the cover crops planted in the corn-soybean rotation fields.

4.2.4.2 Cover Crop Costs

For fields that were in a corn-soybean rotation, table 4.10 describes the cover crops that were planted and the method of establishment. All the farmers used herbicides to terminate cover crops before planting cash crops, except for radish that is a winter-kill cover crop.

Table 4.10: Cover Crop used in Corn-Soybean Rotation Fields

Cover crop/Mix	**Establishment method**	**Nb. of obs.**	**Nb. of farms**	**State**
Annual Ryegrass	Aerial Seeding	5	2	IL/IA
Cereal Rye	Aerial Seeding/ Drilling	25	2/1	IN/IA
Wheat	Drilling	4	1	IN
Radish	Aerial seeding	1	1	IL
ARG/CRC	Drilling	8	1	IN
ARG/CRC/Radish	Aerial Seeding	8	1	IN
CRC/Cereal Rye/ Radish	Aerial Seeding	4	1	IN

*ARG : Annual ryegrass; CRC: Crimson clover

After regrouping the data by cover crop species and method of establishment, we quantified the cost of each cover crop. The cost of establishment includes the cost of the seed and the cost of planting (aerial or drilling). The cost of termination includes the cost of herbicide and the cost of spraying. However, from the data collected, we were not able to know each category of cost since we asked the farmer to provide the total cost of establishment and termination. Table 4.11 displays the costs for each cover crop within the corn-soybean rotation fields.

Table 4.11: Cover Crop Costs ($/ac)

Cover crop/ Mix	**Cost of establishment**			**Cost of termination**			**Total cost**
	Min	Max	Avg	Min	Max	Avg	
Annual Ryegrass	23.60	30.88	26.69	3.54	22.53	12.14	38.83
Cereal Rye	30.34	47.35	40.55	13.23	15.69	14.02	54.57
Cereal Rye (drilled)	24.11	26.74	24.54	6.81	14.54	8.83	33.37
Wheat (drilled)	21.12	21.24	21.15	10.00	20.00	14.15	35.30
Radish	35.48	35.48	35.48	0.00	0.00	0.00	35.48
80% ARG/ 20% CRC (drilled)	32.18	35.29	33.74	14.87	15.88	15.37	49.11
70% ARG/20% CRC/10% Radish	30.34	33.04	31.69	13.65	14.59	14.12	45.81
20%CRC/ 70%CR/ 10%Radish	52.43	52.43	52.43	15.55	15.55	15.55	67.98

*ARG : Annual ryegrass; CRC: Crimson clover; CR: Cereal Rye

There is a wide range of variability in cover crop costs. Aerial seeded cereal rye is the most expensive single cover crop with a mean cost $15 per acre higher than any other single cover crop. The drilled cereal rye has the lowest cost within the single cover crop group. The difference in establishment cost between the drilled and aerial seeded cereal rye makes sense as drilling is less expensive than aerial seeding. Moreover, less seed is used when drilling compared to aerial seeding because of a better seed to soil contact when drilling. However, the termination cost when aerial seeded is almost twice the cost of cereal rye when drilled. The difference in termination cost comes from the fact that the farmers that were aerial seeding their cover crops used two herbicides in a mix to kill the cover crop, compared to one farmer who was using only one product for the drilled cereal rye. Even if radishes winter-kill, their establishment cost is almost the same as the total average cost for wheat. The cover crop mixes show an average cost that is in general higher than the single cover crop groups, except for the aerial cereal rye.

Pratt (2012) quantified the costs of cover crops from various sources, including interviews with farmers and the internet. In her study, the total cost of cover crops included the cost of establishment, the cost of termination and unexpected costs. Aerial seeding was used as the method of establishment to calculate the establishment cost. To account for variability in the costs, PERT and triangular probability distributions were tested. The table 4.12 shows the estimated results for selected cover crop costs.

Table 4.12: Total Cost ($/ac) with Risk Distributions

Cover Crop/Mix	**PERT**	**Triangular**
Annual Ryegrass	34.42	35.78
Cereal Rye	39.51	41.91
Oilseed Radish	39.92	42.65
60% CRC/ 40% ARG	38.05	40.43
60 % ARG/40% Oilseed Radish	36.45	38.39

*ARG : Annual ryegrass; CRC: Crimson clover

For annual ryegrass and cereal rye, the costs quantified in table 4.11 are higher than the costs from Pratt, and she included unexpected costs in the calculation. For oilseed radish, the cost from Pratt is slightly higher than our estimated cost. This is because Pratt added a termination cost and the seeding rates are different. The crimson clover and annual ryegrass mix have a higher estimated average total cost compared to Pratt, even if the mix was drilled. Overall, the cost estimates are not comparable since the techniques used to manage and grow cover crops are site specific. However, overall, the estimates are not very different between Pratt and our study.

In the next section, we will review the answers of farmers to the qualitative questions in order to understand their perceptions of cover crops.

4.2.5 Farmer’s Perceptions of Cover Crops

A total of 19 farmers responded to the questions. Some farmers provided data on cover crop and non-cover crop fields. However, they responded to the questions for cover crop growers. A total of 14 farmers responded to the questions for cover crop growers, and five farmers responded to the question for non-cover crop growers. However, one farmer responded to the cover crop grower questions, even if he didn’t start growing cover crops yet.

For cover crop growers, the first question asked was when they started to consistently plant cover crops in their fields. Table 4.13 shows the start year for planting cover crops by farm. As you can see, most of the farmers interviewed started on or after 2000. However, three farmers said that they started 25 years ago in 1990 or 1986.

Table 4.13: Start Year of Cover Crops by Farm

Farm number	Year
7	1986
2	1990
15	1990
6	2000
9	2004
21	2005
1	2008
12	2008
14	2008
5	2009
13	2010
10	2012
17	2013

All the cover crop farmers interviewed responded that the main reason they grow cover crops is to control soil erosion. The second main reason is the improvement in soil health, and the final one is the increase of soil fertility. Most of the farmers mentioned that they have been in no-till systems for a long time before adopting cover crops. One farmer said: “we have been in no-till for about 25 years, and cover crops seemed to be the next step.” Another farmer mentioned that it reduces the cost of feed for cattle since his cattle graze his cover crops.

For eight of the 14 farmers, the ease and timing of the establishment and termination are the main criteria they look at when choosing a cover crop. Four of the farmers mentioned that they also look at the price of the seed in combination with rapid growth. Other specific criteria include root depth and nutrient scavenger crops.

For all the cover crop growers, the major benefit is the protection against soil erosion. Most of them have seen their soil structure improved with less compact soils.

Finally, two of the farmers that grow cereal rye mentioned that this cover crop is a good weed suppressor in their fields.

For a majority of the farmers interviewed the biggest challenge when growing cover crops is the timing of the establishment and the method of establishment. Their main issue is to figure out the best timing for seeding the cover crop and the best method. Most farmers mentioned that they preferred aerial seeding because it required less labor and time compared to drilling. Also, it allows them to seed the cover crop before the busy harvest season of corn and soybeans. However, one farmer mentioned that oats are not heavy enough to be flown on the soil surface, so they have to be drilled. Another challenge is also the timing of termination and that sometimes cover crops are hard to kill.

Eight of the cover crop farmers have received cost share assistance for growing cover crops, particularly through EQIP or CSP. All of them mentioned that the program is not an incentive for them to plant cover crops and that they would plant them nevertheless. However, six farmers indicated that they have not received any cost share assistance. Most of them didn't provide further explanation.

For the five farmers interviewed that don't plant cover crops, the main reason for why they don't grow cover crop is the extra time management and labor needed in order to introduce cover crops in their farming system. Also, some of them mentioned the added cost, especially if you use aerial seeding as your method of application. One farmer also said that this practice is fairly new and that he prefers that "early adaptors" of cover crops work out all the problems in order for him to start adopting them.

Overall, for cover crop farmers, soil erosion is the main benefit, and they honestly believe that it improves soil health and soil structure. However, the biggest challenge is the timing and method of establishment and termination. For cover crop farmers, cost share assistance is not considered as an incentive to plant cover crops. For non-cover crop growers, the main reason is the added time management and labor.

After describing the different data collected in the fields, we will now focus on the observations that we have for the corn-soybean rotation fields. In the next section, we will assess the problem encountered in quantifying the benefits of cover crops.

4.3 Assessment of the Data in Corn-Soybean Rotation Fields

In order to compare corn and soybean yields between cover crop fields and non-cover crop fields, we created two datasets that include the observations of these two crops within the corn-soybean rotation. As described in the previous chapter, the dataset listed the farm number, the field number, the year, the cover crops regime, the crop name, the yield, the tillage regime, the soil order, and the slope class. This dataset was created in order to perform a regression analysis to evaluate the effect of cover crops on the corn or soybean yields. Indeed, the theory was to do a panel data regression analysis to quantify the effect of cover crops on corn or soybean yields, by controlling for soil order, soil slope, and tillage regime. The outcome of the regression would, therefore, give us a coefficient for the cover crop dummy variable that we could use in the benefit-cost analysis, as long as it is statistically significant. If the coefficient is positive, then we would use that number as the bushels per acre increase in corn or soybean yields when using a cover crop. If the coefficient had a negative sign, we would use that number as a decrease in yields for corn or soybeans and therefore as a cost in the benefit-cost analysis. However, the high variability in the data and the low number of observations did not allow us to put this theory into practice. We ran the regression analysis, and the results were not statistically significant and therefore not conclusive (Appendix C). In fact, table 4.14 shows the number of observations by category of variables that we have included in the regression analysis.

Table 4.14: Number of Observation per Category for Corn and Soybeans

	Corn		**Soybeans**	
	Cover crops	Non cover crops	Cover crops	Non cover crops
Year				
2013	15	11	9	12
2012	8	11	14	12
2011	12	14	7	11
2010	6	13	11	15
2009	11	15	6	13
Tillage system				
NT	30	44	46	56
OCT	15	19	1	3
CT	7	1	0	4
Soil order				
oll	20	20	20	22
alf	31	25	27	25
ent	0	2	0	3
ert	0	9	0	6
ept	1	8	0	7
Slope class				
0-2%	23	49	24	48
2-6%	9	9	6	11
6-12%	18	6	14	4
12-20%	2	0	3	0

The use of a multiple regression analysis allows us to explicitly control for many other factors that simultaneously affect corn or soybean yields. As we can see in table 4.14, there is an unequal sample size per category and also a very low number of observations in particular categories. For example entisol (ent) and vertisol (ert) have not been observed under cover crops for corn and soybeans. For the slope class, there is no observation under no cover crops for a 12 to 20% slope class. However, a few very low observations make sense, especially for the tillage regime. Of the 52 observations under cover crops in corn, 58% of the observations were in NT, 29% in OCT and only 13% in CT. Most of the farmers interviewed mentioned that they started by adopting conservation tillage practices before introducing cover crops in their farming systems; hence, the low number of observations for conventional tillage under cover crops.

The problems encountered when working on the analysis revealed several limits of the data we have collected, which are described in the next section.

4.4 Limitations of the Data Collected

As previously mentioned, the heterogeneity of the data made the analysis difficult and the results non-conclusive, which is due to several factors.

First, regrouping the soil series into soil orders produced five categories with variable number of observations in each category. Additionally, the multiplicity of crop rotations diminished considerably the number of fields and, therefore, the number of observations that could be used in the analysis, which eventually lowered the degrees of freedom. These limitations arise principally from a lack of selection of participants before the data collection starts.

Other factors influenced the low number of farmers participating in the study. First, the organizations with whom we worked on this project were expected to provide farmers from their projects that could be used in our research. For a number of reasons, many fewer farmers ended up being provided by the partner projects.

The second reason was poor timing of the data collection process. Indeed, farmers were first contacted in June 2014, which is in the early months of the corn and soybean growing season. Consequently, they were busy managing their crops and therefore not available to provide data. The harvest period started in September and ended in November. During that time, no fields of data were collected since it is the busiest period for farmers. However, after the harvest ended, farmers were more willing to cooperate with almost 70% of the fields collected from the end of November to the beginning of February. Hence, the timing of data collection is an important factor to take into consideration when requesting data from farmers.

Another factor that limited the amount of data provided is the substantial amount of data requested. When talking about the study at first, most farmers were interested, but then only a few provided data. One of their reasons is that it is a lot of information to gather, especially if you keep records on paper.

One last element to consider is that there was no financial compensation for the participants when they provided their data. In other projects, farmers may receive compensation, which increases their incentive to provide data.

Understanding the factors that limited the analysis of this study helped us better characterize the data and analysis needed in order to quantify the benefits and costs of cover crops. The next section describes how what we learned could be used to improve design for future research on the subject.

4.5 Future Research Design

As described in the previous sections, each farm is unique and comparing farming practices can be hard. One way to gain information and control for many of the variables is to employ on-farm field trials, commonly strip trials in which identical strips in a field have different management practices such as cover crop or no cover crop. The objective of an on-farm trial is to predict how different options will perform compared to each other under the same environment and cropping systems. Strip trials do a good job of controlling for farmer management, weather, soil type, slope, etc. since they are on the same farm and adjacent to each other. However, the results of strip trials may miss some of the real world variability that comes with whole field farmer data.

In this section, we will present an approach for designing future studies to better quantify the benefits and costs of cover crops. The limitations of this study exposed how important the field selection is. In this design, we will first explain the criteria for selecting the fields. These criteria include less soil type and soil slope heterogeneity, same crop rotation with genetically engineered crops and availability of five years of data for each field. Two selection alternatives will be discussed. Next, we will specify the data that needs to be collected from each field. Recognizing that the original amount of data collected was substantial, we reduced it by investigating first if we can find the data in the literature. Consequently, after describing the data collected from farmers, we will display the data that can be found in the literature and used for the analysis. Next, we will discuss the number of farmers to recruit for this study. Also, other considerations such as providing a financial incentive to farmers will be mentioned. In the end, we will summarize the design and discuss its potential limitations.

4.5.1 Selection of Participants

4.5.1.1 First alternative: Selecting an Area of Study by Soil Region, Soil Slope, and Cover Crop Acreage

The first factor to think about when selecting the participants is the geographical area. This will undeniably reduce the heterogeneity in the soil types, soil slopes, and weather conditions. In order to select the area, we have first explored the literature to find a soil map of Indiana where there is less variability in the soil types. Figure 4.5 is a map that illustrates the soil regions in Indiana constructed by the USDA Natural Resources Conservation Service in cooperation with the Purdue University Agricultural Experiment Station in 1986. Each region represents a parent material with the representative soil series. In pedology, the parent material is the initial state of the solid matter making up a soil. This map clearly shows that the central and northeastern areas of Indiana have less diversity in soil regions (7, 8 and 9) compared to other areas of the state. Additionally, figure 4.6 is a map of the shaded relief in Indiana that shows that the area corresponding to these soil regions are for the most part nearly level. Consequently, the area regrouping soil regions seven, eight and nine which is approximately half of the state, seems to be the less diverse concerning soil regions and slope.

However, soil region and slope are not the only factors to take into account when selecting the area of the study. We need to ensure that there are farmers that grow cover crops in that region to be able to quantify the differences in yields between cover crop and non-cover crop fields. The Indiana State Department of Agriculture calculates every year the number of acres that were funded by different state and federal programs such as EQIP or CSP to grow cover crops. Figure 4.7 is a map of the cover crop acreage funded by county in 2014. Note that this map does not show the farmers that planted cover crops without financial support.

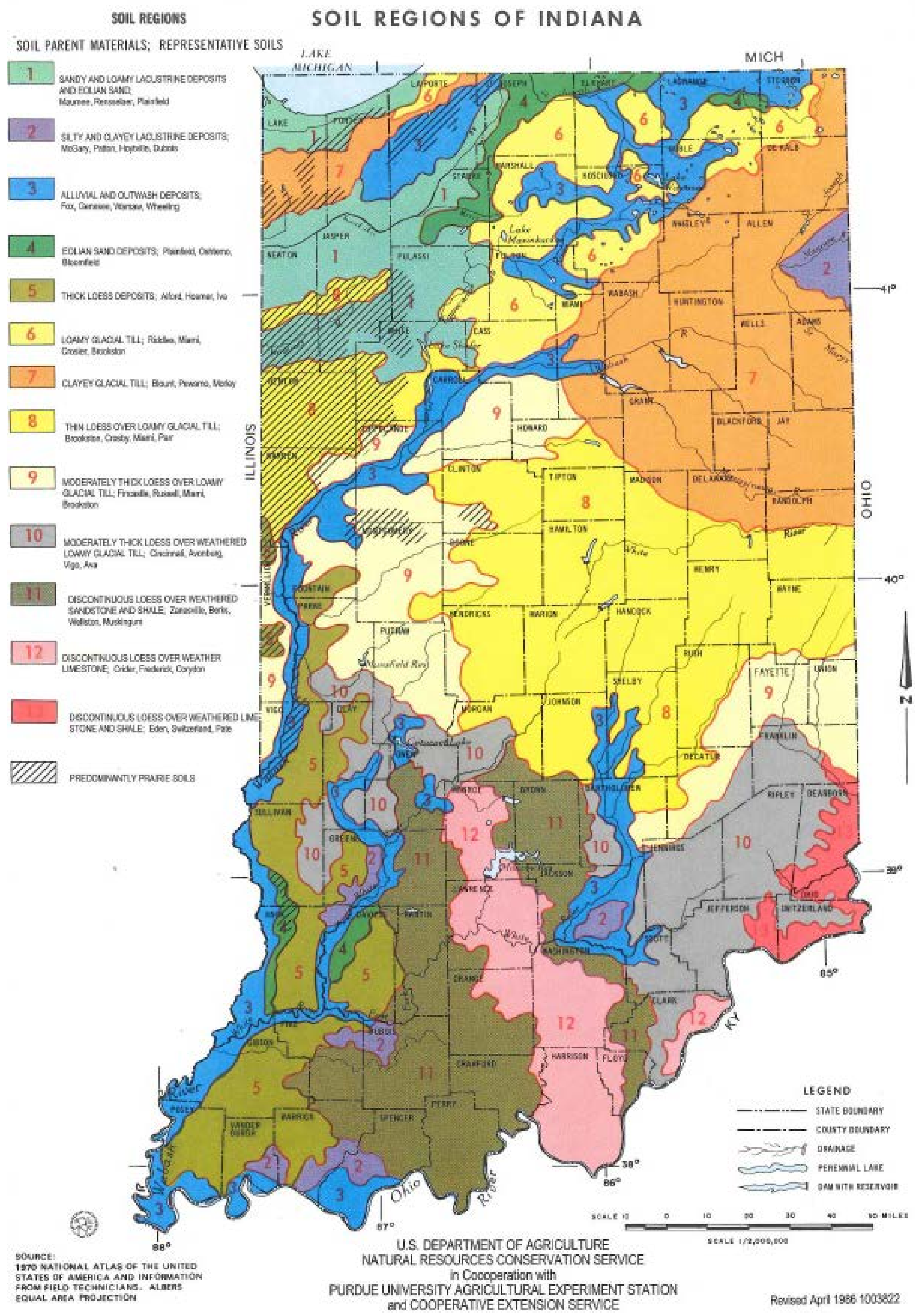


Figure 4.5: Soil Regions of Indiana

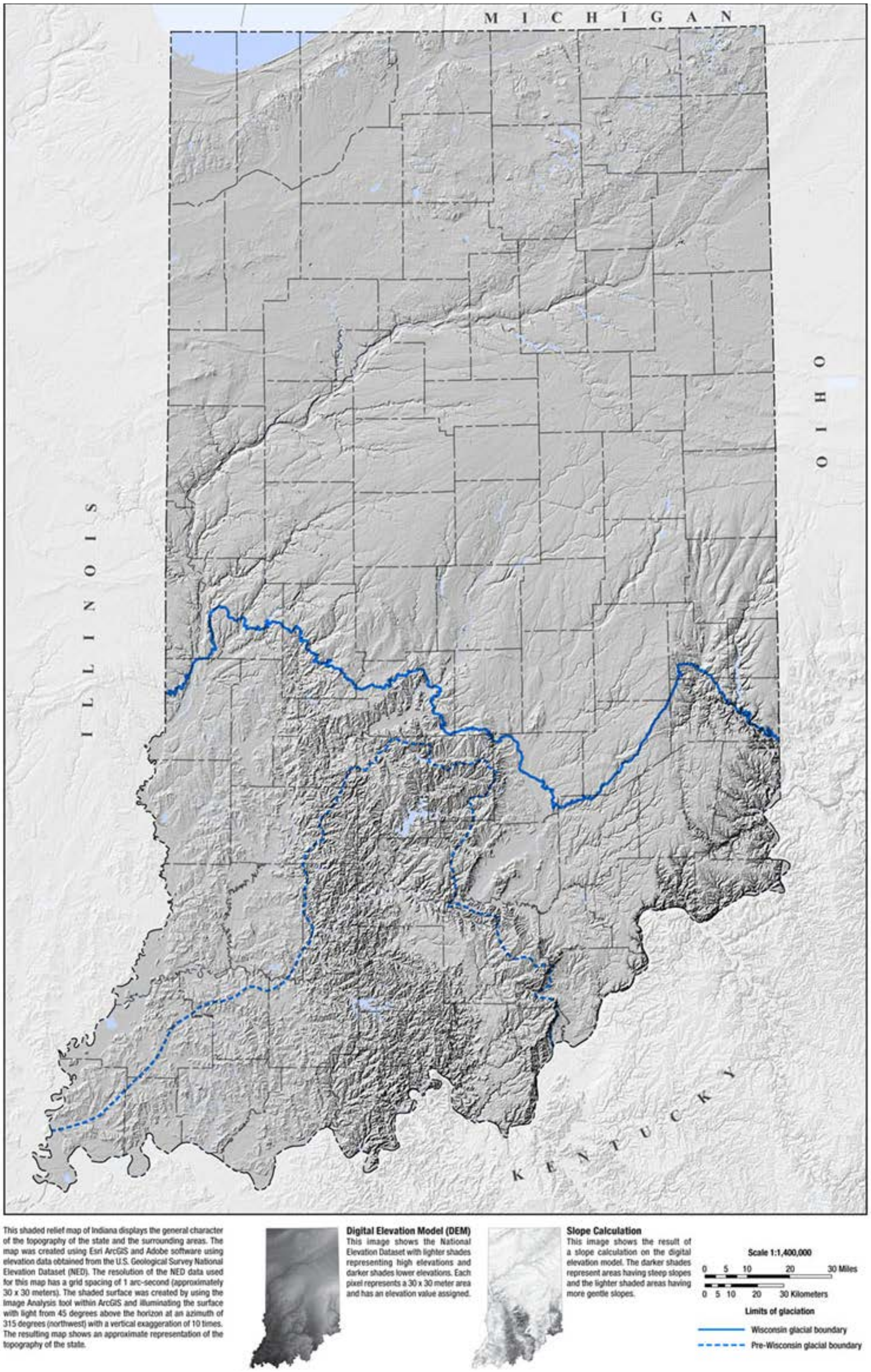


Figure 4.6: Shaded Relief Map of Indiana

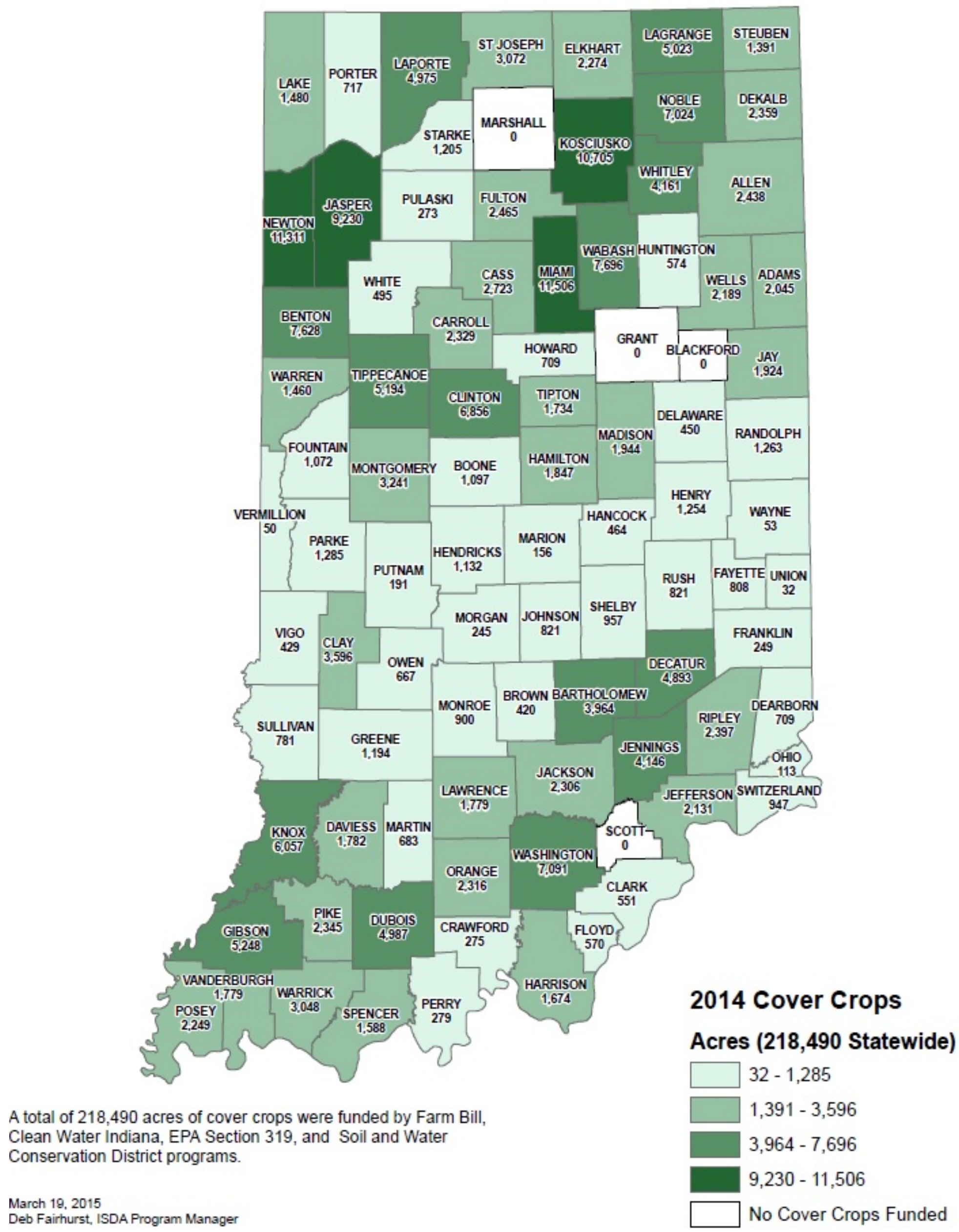


Figure 4.7: Cover Crop Acreage Funded by State and Federal Programs in 2014

In table 4.15, we combined county data on the cover crop acreage funded in 2014, the total acres of farm land from the U.S. Census of Agriculture in 2012 and the soil region number from the map in figure 4.5.

Table 4.15: County Selection by Cover Crop Share of Total Area and Soil Region

County	**Total acres of cover crops funded (2014)**	**Total acres in farm land (2012)**	**Share of cover crops land in the total farm land (%)**	**Dominant soil region (number)**
MIAMI	11,506	175,276	6.56%	7
WABASH	7,696	197,588	3.89%	7
NOBLE	7,024	181,491	3.87%	7
CLINTON	6,856	223,428	3.07%	8
BENTON	7,628	254,245	3.00%	8
WHITLEY	4,161	140,099	2.97%	7
DECATUR	4,893	186,528	2.62%	9
TIPPECANOE	5,194	220,199	2.36%	9
DEKALB	2,359	160,894	1.47%	7
HAMILTON	1,847	130,854	1.41%	8
TIPTON	1,734	145,181	1.19%	8
CARROLL	2,329	204,090	1.14%	9
MONTGOMERY	3,241	286,949	1.13%	9
JAY	1,924	175,770	1.09%	7
WELLS	2,189	200,334	1.09%	7
FAYETTE	808	78,242	1.03%	9

Table 4.15 displays a total of 16 counties selected. From figure 4.6, there were 42 counties with soil regions seven, eight, or nine. We excluded 26 counties where the share of cover crop in the farmland area was less than one percent. By selecting these particular counties, we ensured that there are only three soil regions, gentle soil slopes, and the existence of cover crop farmers. Moreover, we are controlling for weather conditions such as temperature and precipitation that we assume are very similar across these counties.

Now that we have selected the area of the study, we need to choose specific crop rotations. Assuming that most farmers in Indiana grow continuous corn or corn and/or soybeans in a rotation, we can select fields where the rotation only consists of these two crops. It can be a corn-soybeans rotation, or a corn-corn-soybeans rotation or continuous corn. We need to ensure that no other crop other than corn and soybeans is included in the study. Also, by ensuring that corn and soybeans are genetically engineered, we will be able to compare the crop yields.

At this point, we have controlled for the field location (hence soil regions and slope), the rotation and the seed biotech traits of the crops. In order to conduct a long-term analysis of the economics of cover crops, we need to collect at least five years of data. We chose to focus on five years because it is probably what most farmers have. In fact, during our data collection process, we have realized that requesting 10-year record was too ambitious and is not in most cases realistic.

Once we know that the participants have at least five years of historic data, we need to know if they grow cover crops or not. If they don’t grow cover crops, then the participant is selected and can provide data for non-cover crop fields. If they grow cover crops, we need to ensure that they have been growing cover crops for at least five years. Indeed, one of the aspects to take into account when growing cover crops is that the benefit are not noticed in the first year of planting but most likely in the longer term. Figure 4.8 summarizes the steps taken in selecting the participants for the future study.

As described in section 4.1, 16 fields were collected from the central region of Indiana. It is in our interest to look at the characteristics of those fields and see if our selection process is realistic. First, there were eight cover crop fields and eight non-cover crop fields. These fields came from Hancock, Fountain, Tippecanoe, and Vermillion counties. Only Tippecanoe county is included in the list of counties selected. However, all the fields were in a corn-soybean rotation, so this makes it realistic to request only fields with corn and/or soybeans. Two of the fields had a corn-soybean rotation up until 2013, but in 2013 the farmer decided to plant popcorn. Therefore, the popcorn observations would not be included in the analysis. The field included 40 observations of corn and 36 observations of soybeans. Corn yields in cover crop and non-cover crop fields were almost the same at an average of 178.3 bushels per acre with cover crops and 178.8 bushels per acre without cover crops. However, soybean yields without cover crops were higher by three bushels compared to soybean yields with cover crops. These differences in yields are not statistically significant. Another characteristic is that the fields had only three different soils: Alfisol, Mollisol and Vertisol. All the fields had a slope of 0 to 2%, except one field that had a 2 to 6% slope. Moreover, all the farmers in that region provided five years of data for cover crop and non-cover crop fields. Finally, three fields of eight had cover crops grown for four years, but all the other one were grown for six years. Therefore, this selection process is feasible in the reality and can significantly reduce the heterogeneity in the data.

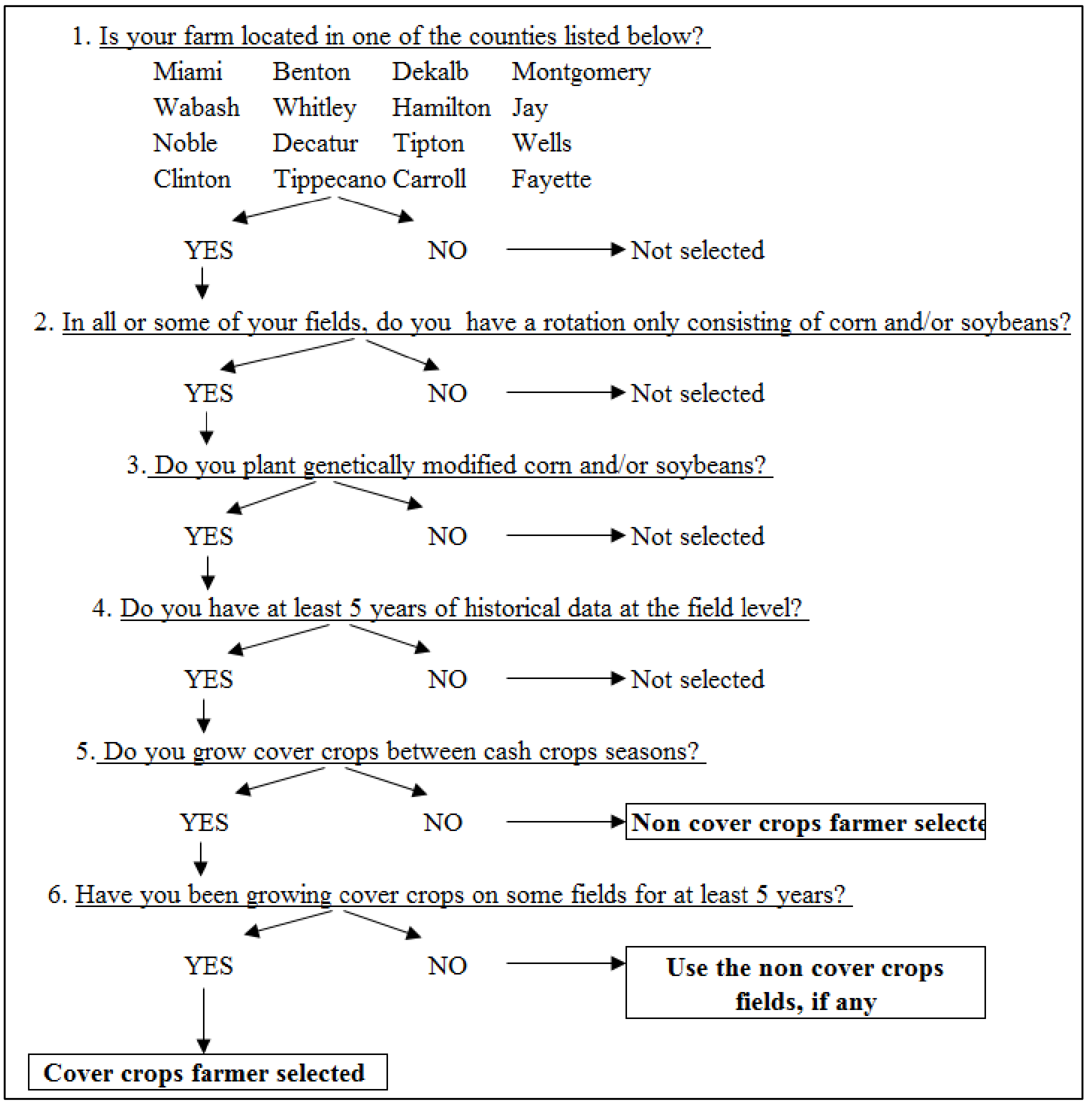


Figure 4.8: Participant Selection Process

This selection process would help us have less variability in the data collected. However, soil regions are not soil types and do not take into account all the characteristics of the soil. Another alternative exists, especially for corn data, which is described in the next section.

4.5.1.2 Second alternative: Using the Soil Productivity Ranking Factor

Dr. Phillip Owens, associate professor of agronomy at Purdue University and his post-doctorate research assistant Dr. Jenette Ashtekar developed a soil productivity ranking factor (SRF) for each soil map unit in each county of Indiana (Owens & Ashtekar, 2013). A mapping unit comprises one or more soil series. The SRF was generated from the corn yield prediction of the Dideriksen Model. In this section, we will briefly describe the Dideriksen model, how it was used to calculate the SRF, and then present the new area of study selected.

The Dideriksen model is used to assess corn yield changes in soil with respect to a set index yield potential. It is named after Ray Dideriksen, who was the former Indiana State Soil scientist who developed the model in 1972. In 1976, Walker updated the model by adding other soil factors that can affect yield (Walker, 1976). The model incorporates 14 soil characteristics that are considered to have either a positive or a negative effect on corn yields. These characteristics include soil material, base saturation, slope, erosion, the thickness and organic matter content of surface horizons, the natural soil drainage, and many others. For each characteristic, if the effect is positive, then bushels per acre are added, if the effect is negative, then bushels per acre of corn are subtracted. The model assumes average farm management at a level required for crop production and also that drainage systems are in place for wet soils.

To create the SRF, the predicted corn yield from the Dideriksen model of each soil map unit was divided by 145 bushels per acre. According to Owens and Ashtekar (2013), this value was the model yield for the Miami soil mapping unit, which was considered as the average corn producing soil in Indiana. Moreover, as reported by the USDA National Agricultural Statistics Services, the average corn grain yield in Indiana in 2011 was close to 145 bushels per acre (USDA, 2012). The SRF ranges from 0.50 to 1.31 in Indiana. Each mapping unit with a corn yield of 73 bushels per acre or lower was given the minimum SRF. Table 4.16 shows an example of SRF for each mapping unit in a few counties of Indiana.

Table 4.16: Example of Soil Productivity Ranking Factors for Selected Counties and Mapping Units

County	MU Symbol	MU Name	SRF
Adams	BcB	Blount silt loam, 1 to 4 percent slopes	0.97
Jasper	AyB	Ayr loamy fine sand, 1 to 4 percent slopes	0.86
Knox	IoA	Iona silt loam, 0 to 2 percent slopes	1.10
Miami	Re	Rensselaer loam	1.28
Tippecanoe	Du	Drummer silty clay loams	1.28
Wabash	MfC2	Miami loam, 6 to 12 percent slopes, eroded	0.90

*MU: Mapping Unit

Therefore, SRF can be included in the future design to account for soil factors that can affect the corn yield. SRF was only calculated for corn considering that corn is more sensitive to changes in soil properties than soybeans. By using the SRF, we are not constrained to select an area with less variability in soil type. However, we still need to select an area where the weather conditions are homogeneous and where there are cover crop farmers. Figure 4.9 shows the precipitation levels in Indiana from 1981 to 2010. We can clearly notice three areas: the northern area that receives between 30 to 42 inches of rainfall, the central region that receives between 42 to 45 inches of rainfall and finally the southern region with abundant rainfall from 45 to over 48 inches.

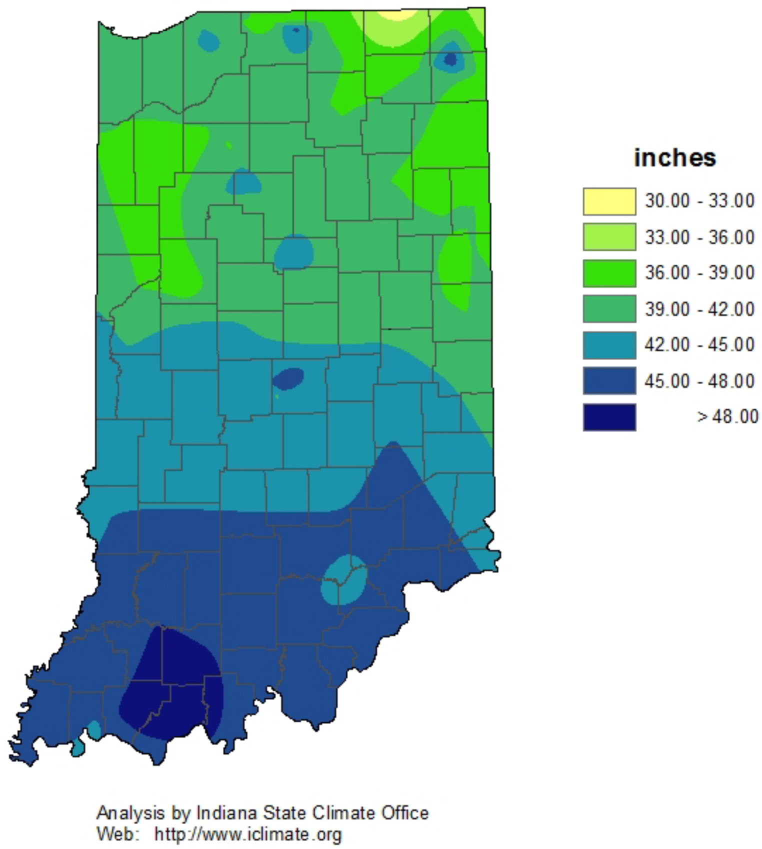


Figure 4.9: Precipitation Levels in Indiana from 1981 to 2010

By looking at the map in figure 4.7, we can see that most of cover crop farmers are either located in the northern region or the southern region of Indiana. Hence, we decided to focus on the northern area where precipitation varies from 30 inches to 42 inches per year. In the southern region of Indiana, a lot of farmers have a specialized rotation with double crop soybeans because the weather allows it. Therefore, that would complicate the process in selecting farms with only corn and/or soybean rotation fields. Moreover, in figure 4.10, we can see that the northern region of Indiana with average temperatures ranging from 24 to 30 degrees Fahrenheit coincide with the northern region selected for the precipitation.

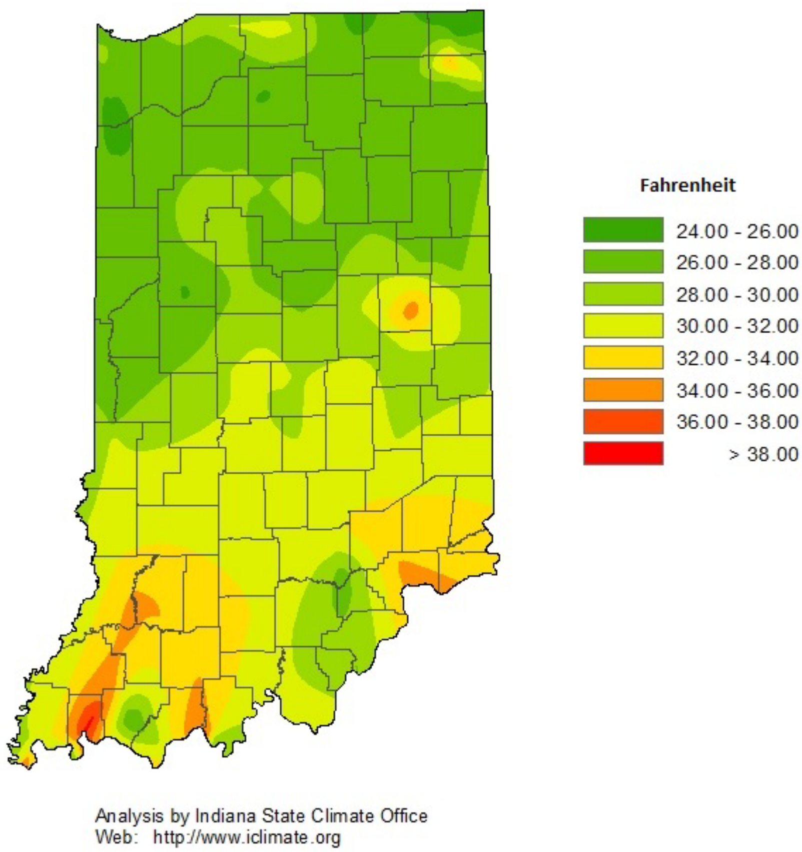


Figure 4.10: Temperature Levels in Indiana from 1981 to 2010

By combining the counties located in the northern region of the state with the data on cover crop acreage in each county, we have selected 24 counties, displayed in table 4.17, where the cover crop acreage represents more than one percent of the county total farm land.

Table 4.17: Second Alternative - County Selection by Cover Crop Share in the Northern Region of Indiana

County	**Total acres of cover crops funded (2014)**	**Total acres in farm land (2012)**	**Share of cover crops land in the total farm land (%)**
MIAMI	11,506	175,276	6.56%
NEWTON	11,311	192,030	5.89%
KOSCIUSKO	10,705	254,847	4.20%
WABASH	7,696	197,588	3.89%
NOBLE	7,024	181,491	3.87%
JASPER	9,230	282,831	3.26%
CLINTON	6,856	223,428	3.07%
BENTON	7,628	254,245	3.00%
WHITLEY	4,161	140,099	2.97%
LAGRANGE	5,023	204,092	2.46%
TIPPECANOE	5,194	220,199	2.36%
LAPORTE	4,975	227,865	2.18%
ST JOSEPH	3,072	151,975	2.02%
DEKALB	2,359	160,894	1.47%
HAMILTON	1,847	130,854	1.41%
CASS	2,723	200,257	1.36%
STEUBEN	1,391	104,570	1.33%
ELKHART	2,274	172,847	1.32%
FULTON	2,465	188,411	1.31%
CARROLL	2,329	204,090	1.14%
MONTGOMERY	3,241	286,949	1.13%
LAKE	1,480	133,064	1.11%
JAY	1,924	175,770	1.09%
WELLS	2,189	200,334	1.09%

Thus, the only question that changes from the farmer selection process presented in figure 4.8 is the first question where more counties are added to the list. Then, future researchers can follow the selection process from question two to six to ensure less variability in crop rotation, crop characteristics and the availability of historical field data.

By choosing one of the proposed alternatives to select participants, we controlled for the soil characteristics and the weather conditions, and we ensured less heterogeneity in crop characteristics. After selecting the participants, we can collect the variables of interest for the study. The next section describes the data that will be collected for cover crop farmers and non-cover crop farmers and the motivation behind it.

4.5.2 Data Collection

In this section, we will first describe the data that will be collected from both cover crop and non-cover crop fields for both alternatives. Then we will cover the other data needed for the analysis that can be found in the literature.

4.5.2.1 Data collected from Selected Farms

If the first alternative of the selection process is used, table 4.18 lists the data that will be collected for both cover crop and non-cover crop fields over a five-year period as well as the motivation for each variable collected.

Table 4.18: First Alternative - Data and Motivation for Cover Crop and Non-Cover Crop Fields

Data	**Motivation**
Number of acres in the field	Description purposes
Corn or soybean yield (bu./ac)	Yield for each crop will be the dependent variable in the regression model
Slope class of the field	Variable in the regression model
Tillage system	Variable in the regression model
Total amount of N (lbs./ac) only for corn years	Variable in the regression model
If field somewhat poorly/ poorly/ very poorly drained: Drainage system of the field	Variable in the regression model

Field slope, tillage regime, drainage system and nitrogen rate for corn are important factors that influence the cash crop yield. Therefore, they need to be taken into account in the regression model. Other control variables that should be known after selecting the farm are soil type and soil slope.

Even if we assumed that the field slope would be in nearly level in the region selected, we still need to collect the data to make sure we don’t have high sloping fields.

Therefore, the participant will be able to choose from one of the three classes of field slope: 0 to 2%, 2 to 6%, and 6 to 12%.

For the tillage system, the participants will be able to choose from one of the three following categories:

- Conventional tillage that leaves less than 15% residue on the soil surface
- No-tillage that leaves more than 50% of residue on the soil surface
- Other conservation tillage that leaves between 15 to 50 % of residue cover on the soil surface

This way, there won't be any confusion in the way each participant can describe their tillage system and also less variability in the data collected.

In the United States, there exist seven natural drainage classes for soils: excessively drained, somewhat excessively drained, well drained, moderately well drained, somewhat poorly drained, poorly drained, and very poorly drained (Soil Survey Division Staff, 1993). Before asking the farmers if their fields have a drainage system implemented, we need to know the natural drainage class of the field. If the field is somewhat poorly drained, poorly drained or very poorly drained, then we can collect information on the type of drainage system that they implemented in the field. Like the tillage regime, the participant will choose between two types of drainage systems or no drainage:

- Surface drainage that includes bedded lands, basins, and terraces
- Subsurface drainage that includes tiles, ditches, and channels
- No drainage if the field does not have any drainage system and is poorly drained

If future researchers decide to use the second alternative to select the farms, then the data collected is slightly changed. Table 4.19 lists the data needed and the motivation behind it.

Table 4.19: Second alternative - Data and Motivation for Cover Crop and Non-Cover Crop Fields

Data	Motivation
Number of acres in the field	Description purposes
Soil series and slope class of the field	Find the SRF for the field, which will be a variable in the regression model
Corn or soybean yield (bu. /ac)	Yield for each crop will be the dependent variable in the regression model
Tillage system	Variable in the regression model
Total amount of N (lbs./ac) only for corn years	Variable in the regression model

If we follow the second alternative, we need to know what the dominant soil series of each field is in order to find the SRF. Then the SRF will be used in the regression model to control for the soil properties. Also, we won't need to collect data on the drainage system since it is included in the calculation of the SRF.

If the field is a cover crop field, additional information needs to be collected, which is described in the table 4.20.

Table 4.20: Data and Motivation for Cover Crop Fields

Data	Motivation
Cover crop and seeding rate (in lbs./ac)	Quantify the establishment cost
Seeding method	Quantify the establishment cost
Herbicide product used to terminate the cover crop and application rate	Quantify the termination cost
If the participant received cost share assistance: name of the program	Quantify private benefits of cover crops or social costs of cover crops

For the herbicide section, we need first to ask the participants if they would apply the herbicides at the same rate even if they didn't grow cover crops. If the response is "yes", then the herbicide is not considered as an extra cost for the farmer, and it should not be included as an extra cost of cover crops in the benefit-cost analysis. But if the response is "no", then we have to collect data on the herbicide used and application rate to be able to calculate the termination cost of cover crops.

The amount of data collected from farmers is reduced compared to the original data collected for this study. However, it means that other data needs to be found in the literature in order to do the analysis. The next section describes the data that can be found in the literature and why it is needed for the analysis.

4.5.2.2 Data Collected from the Literature

Table 4.21 displays the data that is needed in order to quantify the benefits and costs of cover crops in future studies, which can be found in the literature.

Table 4.21: Data Collected from the Literature and Motivation

Data	**Motivation**
Average growing season temperature (May-Sept)	Variable for the regression model
Average growing season precipitation (May-Sept)	Variable for the regression model
Corn and soybean prices	Quantify private benefits
Cash crop production costs (seed, fertilizers, herbicides, machinery repairs and others)	Quantify private costs
Cover crop seed cost	Quantify the establishment cost for cover crops
Cover crop seeding method cost	Quantify the establishment cost for cover crops
Herbicide cost of herbicides used in terminating the cover crops and cost of spraying	Quantify the termination cost for cover crops

Temperature and precipitation are important weather factors that influence the cash crop yields, hence including them as independent variables is essential. The weather information can be found on several databases online such as the National Oceanic and Atmosphere Administration Data Tools or the Midwest Regional Climate Center.

Additionally, the Purdue Crop Cost and Return Guide does a great job in estimating the harvest price for a selection of cash crops, input costs such as fertilizer, seed, pesticides, but also fuel machinery repairs and other costs (Dobbins *et al.*, 2014). We will assume that the cash crop production cost will be the same for cover crop and non-cover crop farmers.

Cover crop seed cost can be found from several websites from seed suppliers such as Adams-Briscoe Seed Company, The CISCO Companies, Green Cover Seed, Albert

Lea Seed and many others. The cost of herbicide can be found on different websites from herbicide suppliers. The cost of spraying the herbicide and the cost of seeding the cover crops will be less easy to find in the literature. The estimation of custom rates can be done by interviewing experts such as crop advisors, field staff, agronomists and other experts in the considered county.

4.5.3 Methodology Overview

After collecting the relevant data per field in each farm, the data need to be organized in datasets in order to complete the analysis required for this study. Several data sets can be created for each cash crop considered within a particular rotation. For example, rotational corn, rotational soybeans or continuous corn. Corn or soybean yields will be the dependent variables in the regression analysis. The independent variables will include the panel time variables, the cover crop regime, and other control variables. The control variables are all the variables that we need to control for when looking at the difference in yields between cover crop and non-cover crop fields. By using the first alternative, the control variables include the soil region, the soil slope, the tillage regime, the drainage system, the average temperature, and precipitation. Also, nitrogen application will be added as a variable in corn datasets. If the second alternative is chosen, the control variables will only include the soil ranking factor (SRF), the tillage regime, the average temperature, and the average precipitation. The use of a multiple regression analysis evaluates the difference in yields between cover crop and non-cover crop field by controlling for many other factors that simultaneously affect corn or soybean yields. That way, the yield increase or decrease suggested from the coefficient on the cover crop regime variable will be used for quantifying either a benefit or a cost of cover crops in the benefit-cost analysis. The benefit-cost analysis will consider two cases: “with” cover crops and “without” cover crops. In each case, the annual yield gain will be used to compare with cover crop costs. Of course, soil erosion and other benefits of cover crops need to be included as well.

The low number of fields in this study demonstrated how important the number of observations is. Therefore, we need to think about how many farmers we should recruit for the future study proposed in this section. Several theories exist on how to determine a sample size. However, for this study, we cannot determine the sample size because we are selecting farms based on specific criteria which imply that it is not random. Also, the sample will not be representative of the population because we will need more than 1% of the fields under cover crops to be able to quantify the differences in yields between cover crop and non-cover crop fields. That being said, Israel (1992) does a great job at summarizing the different sampling procedures. Tables at the end of his paper suggest that for a large population (100,000), a sample size of 395 is needed for a 5% precision level and with a 95% confidence interval. At the 10% level, the sample size suggested is 100. Also, Israel mentions that the primary consideration in estimating the sample size is to make sure that is appropriate for the analysis that is planned. Since we are using a multiple regression analysis with several variables, we need to ensure that we will have enough degrees of freedom in order to have statistically significant results. Israel indicates that "a good sample size, e.g. 200-500, is needed for multiple regression, analysis of covariance or log-linear analysis". Let's take the midpoint of this range and see how it would fit in our study. If 350 fields are needed, and we are collecting five fields per farm that means that 70 farmers need to be recruited following the selection process described in figure 4.9. Also, since one observation is one year of data within one field, that means that we will have 1750 observation total, which is more than enough for the regression analysis.

One of the limitations of this study is that the participant was not financially rewarded for providing data. Several studies demonstrated that financial incentives lead to higher response rated compared to no incentive (Shaw *et al.* (2001); Edwards *et al.* (2002)). Therefore, the future research needs to include financial reward to farmers in order to have a higher response rate and more attention to data quality.

4.5.4 Summary and Limitations of this Design

The suggested data and analysis framework should help better quantify the benefit and costs of cover crops. The farmer's selection process will enable the researchers to have less heterogeneity in the soil characteristics and crop rotation. The data required by farmers is not complicated and reduced compared to the original data collected for this study. Other relevant data can be found by searching various sources in the literature. We have estimated that 350 fields of data need to be collected in order to perform the quantitative analysis, which means that 70 farmers need to be recruited. Finally, rewarding financially the farmer is a good incentive in order to increase the response rate.

An important limitation of this design is that the results will only be valid for the particular characteristics of the design. In other words, the results will only be valid for the selected soil regions, soil slope, crop rotation, weather condition and other factors selected. However, the process can be repeated by selecting other parameters such as another geographical area with different soil regions and soil slope or other field crop rotations.

CHAPTER 5. CONCLUSIONS

Conservation practices such as cover crops have been shown to alleviate the effects of soil degradation by providing numerous benefits. The benefits include the reduction in soil erosion, reduction in soil compaction, an increase of soil fertility and a better control of weeds. However, surveys and studies showed that cover crop use in the United States is minimal. This is likely due to the farmers' perception that costs of cover crops are higher than the benefits. This study aimed to quantify the benefits and costs of cover crops in the Midwest. The method consisted of collecting relevant data by fields on several farms and comparing yields between cover crops and non-cover crop fields. However, we were not able to complete the quantitative analysis for several reasons. By understanding the limitations of our dataset, we were able to design a better framework for future research in order to quantify the benefits and costs of cover crops. This chapter provides a summary of the findings from the data collected and their limitations followed by a summary of the suggested framework.

5.1 Summary of Findings and Limitations

The data collected had several characteristics. First, on the 82 fields of data collected, the type of crop rotations was diverse. Around 57% of the fields were in a corn-soybean rotation, followed by 17% in a wheat or oats- corn-soybean rotation, with the rest in various other rotations. Most of the fields were under no-tillage systems which demonstrates that the sample of data collected is not representative. Moreover, a few fields had crops that were not genetically modified crops. The literature suggests that in order to compare yields between cover crop and non-cover crop fields, the crops need to be in the same crop rotation with the same seed biotech traits. These aspects of the crops reduced consequently the number of fields that could be used in the analysis.

Consequently, the difference in the cash crop yields between cover crop and non-cover crop fields reported were not statistically significant.

Concerning fertilizers, most farmers used commercial fertilizers. However, a few farmers applied animal manure to their fields which resulted in high nitrogen application rates. The descriptive statistics suggested that the nitrogen application on corn in cover crop fields is higher than in non-cover crop fields. The herbicides used were mostly glyphosate, atrazine, and 2,4-D, which concords with what most farmers use in the United States.

Cover crops were either planted in a mix or as a single cover crop. The mixes included one cover crop in each of the following families: grasses, brassicas, and legumes. The most used grass cover crop was cereal rye, followed by annual rye-grass. The most used legume was crimson clover, and the most used Brassica was radishes. Within corn-soybean rotation fields, cover crop costs varied. The average total cost ranged from $33 to $68 per acre using 2013 prices. The most expensive mix of cover crop included crimson clover, cereal rye, and radish. The less expensive cover crop was a drilled cereal rye. It was not easy to compare the costs of this sample with the literature since there are significant differences in costs between the different methods of establishment. However, the results suggest that they were close to the estimates in the literature. For cover crop growers, the main benefit of cover crops is the control of soil erosion. The biggest challenge is the timing and method of establishment and termination. For non-cover crop growers, the main reason for not growing cover crops are the added time management and labor.

The conception of a dataset for corn and soybeans helped better visualize the data collected. The dataset included the cash crop yield, the year, the cover crop regime, the tillage regime, the soil order and the soil slope. It was created in order to perform a multiple regression analysis to quantify the difference in yields between cover crop and non-cover crop fields. Given the fact that each farm is unique, the data collected resulted in a high variability and heterogeneity of the crop rotation, field soil types and soil slopes. These characteristics limited the completion of the quantitative analysis. Also, the fact that data collection was done when farmers were the busiest and that there was no financial compensation provided are other factors that limited the amount of fields collected.

Understanding the factors that limited the analysis of this study helped us better characterize the data and analysis needed in order to quantify the benefits and costs of cover crops. The next section summarizes the design for future research that we developed in this study.

5.2 Summary of the Future Research Design

The design of future research suggested in the study will help improve the future studies on the benefits and costs of cover crops. The first step was to select participants by following desired criteria. In the first alternative, we aimed to reduce the heterogeneity in the soil type, soil slope and to some extent weather. Therefore, we chose an adequate area comprised of three soil regions and gently sloping fields. The presence of cover crop farmers is also an important criterion to consider. We can find non-cover crop farmers everywhere, but it is not the case for cover crop farmers. As a result, 16 counties in Indiana were selected with at least one percent of the total cropland receiving cover crop assistance. The second proposed alternative uses the soil productivity ranking factor to account for the effect of the soil characteristics on corn. Therefore, we were able to select an area with homogeneous weather condition and the presence of cover crop farmers. As a result, 24 counties in Indiana were selected by choosing this method. After selecting the area, we focused on the crop characteristics desired, including the same crop rotation and seed biotech traits. Since corn-soybean rotation is predominant in Indiana, we recommend selecting only farms that have fields with a rotation that contain genetically modified corn and/or soybeans. Finally, the last criterion in the selection process was the availability of five years of data for both cover crop and non-cover crop farmers. A field would be considered as a cover crop field only if cover crops were planted for at least five years in the field.

After selecting farmers based on several criteria, we listed the data that needs to be collected from cover crop and non-cover crop fields. This data include several variables that will be used in the regression analysis and the benefit-cost analysis. One characteristic of the data collection is that the amount of data requested is substantially reduced compared to the original data collected for the study. We decided to assess all the data that can be found in the literature to minimize the time spent by a farmer to gather the information. Moreover, a new characteristic of the data is the inclusion of weather data such as temperature and precipitation that was initially omitted from the analysis.

One of the biggest limitations of the data collected is the low number of observations. By looking at what the literature suggests, we have estimated that 350 fields are needed for the analysis, which involves recruiting 70 farmers for the study. Also, in order to reach the desired number of participants, we also suggest rewarding each participant financially for providing data on their fields.

Overall, this framework should be a good process to follow in order to quantify the benefits and costs of cover crops. However, the results of this framework are only valid for the soil regions, soil slopes, crop rotations, and other criteria selected. The process can be repeated by selecting another area with different soil regions, soil slope and choosing other selection criteria. In other words, we have developed a methodology that can be replicated in any other region. With repeated studies of this type, we will eventually have enough solid evidence from actual farm fields to answer questions regarding the economic impacts of cover crops.

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APPENDICES

Appendix A Guide to the data

BENEFIT-COST ANALYSIS OF COVER CROPS

GUIDE TO THE DATA STRUCTURE

This study is funded by the U.S. Department of Agriculture with the goal of quantifying the long term benefits and costs of cover crops. The method consists of collecting field data over several years on farms who practice and do not practice cover crops. The objective is to collect data on a significant number of farms in both categories in order to quantify the differences in crop yields, chemical uses, soil organic matter, erosion, etc.

An Excel spreadsheet has been created to collect all the relevant data for this study. This guide describes the data structure. All the section numbers on this guide refer directly to the section numbers on the excel spreadsheet.

1. General information

- Farm code: for confidentiality purposes, data collected on each farm/field will be coded and therefore non-identifiable. Leave this value blank, the researchers will enter a farm code.
- Size of farm: enter the size of your farm in acres.

After completing the general information, the next sheets refer to each field you are providing data on. All the sheets request the same information on the fields. On the file, 7 field sheets have been created, but you can copy one sheet and paste it if you have more field data to share. In fact, the more field data you can provide, the more realistic will be our analysis. Also, please do not choose your best fields to share data on. We need a range of field quality.

2. Cash crop

2.1 Field information

- Number of acres: enter the size of the field in acres.
- Dominant soil type: enter the dominant soil type of the field.
- Slope class/ Percent slope: enter the slope class or the percent slope of the field.
-

2.2 Crop information

In this table and all other tables, data are collected over the past 10 years. If you don’t have 10 years of data, please provide the number of years available. The data should be on consecutive years.

- Crop name: enter the crop name planted on the field each year.

- Yield: enter the crop yield in bushels per acre.
- Seeding rate: enter the seeding rate for each crop. If you use variable seeding rate technology, please insert the average of the seeding rate on that field. Specify the unit of your seeding rate (kg/ac or lbs./ac).
- Seed biotech traits: enter information on the biotech traits of the seed that you used.
- Additional seed treatment: if you treated your seed, specify the product used. If not, leave the cell blank.
- Tillage regime: enter the tillage practice for the field each year.
- Drainage system: enter the type of drainage system.
- Harvest equipment used: please list the equipment used during harvest on each crop every year.

If the information is not changing, you can just enter "same" for other years.

2.3 Chemical use

This section is related to all the chemicals used on the field per year. Please pay attention to the tables as they are each different.

2.3.1 Fertilizers

To facilitate the data collection in this section, we listed some common fertilizers products. For each year, if you see the product that you used on that list, you can directly provide the application rate on the row of the product. If you used a NPK formula, indicate the formula that you used in the column "choice product" and its application rate. If the product is not listed, please provide the information on the product in the row called "Others". If you have multiple other products used, you can insert as many rows as needed in the table. **Please specify if the application rate is the amount of product or the amount of nutrients (N, P, and K) anywhere next to the spreadsheet table or by email.**

2.3.2 Herbicides

For each year, enter the products that you used on that field and their application rate. Please specify the units of the application rate. If you used more than 4 products, you can insert more rows in each year to add other herbicides.
If you didn't plant cover crops in that field, please leave the last 5 columns blank.
If you planted cover crops in that field, specify for each herbicide if it was used as a standard herbicide or to terminate your cover crops (1st pass) or if it was a second pass to terminate cover crops. If it was used to terminate cover crops, enter in the last two columns when you applied the herbicides and how much it cost you in dollars per acre. The cost of termination include everything that you used (chemical, chemical application cost, labor…etc.) in order to kill the cover crops.

2.3.3 Insecticides

For each year, enter the products that you used on that field and their application rate. Please specify the units of the application rate. If you used more than 4 products, you can insert more rows in each year to add other insecticides.

2.3.4 Fungicides

For each year, enter the products that you used on that field and their application rate. Please specify the units of the application rate. If you used more than 4 products, you can insert more rows in each year to add other fungicides.

3. Cover crops

If you didn't plant cover crops on that field, please leave this section blank.

3.1 Establishment

For each year:

– Method: enter the method you used to establish your cover crops.
– Time: enter the date of planting the cover crops.
– Cash crop harvest time: enter the date when you harvested the cash crop.
– Crop: list the cover crop types that you planted on that field.
– Seeding rate: enter the seeding rate associated with each cover crop that you planted.
– Cost: enter the full cost in dollars per acre for establishing your cover crops.

The following table asks you to rate the quality of your cover crop establishment for every year.

3.2 Termination

If you used herbicides to terminate your cover crops, please leave this section blank.
If you used another method to terminate your cover crops, enter the information about:

– Method: enter the method you used to terminate your cover crops.
– Time: enter the date when you terminated your cover crops.
– Cost: enter the full cost of termination of your cover crops in dollars per acre.
–

4. Other information

This section refers to any measurements that you possibly have on your farm for each of these items:

4.1 Soil organic matter
4.2 Soil moisture
4.3 Soil erosion
4.4 Soil compaction

Please provide any available information that you have on each of these items.

5. Qualitative questions

5.1 If you plant cover crops

In this section, we would like to have your perception on cover crops. Please enter your answers below each question.

5.2 If you don't plant cover crops

Please enter your answer below the question.

If you have any questions, comments or concerns about this data structure, you can talk to one of the investigators:

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Thank you for your participation.
June 2014

Appendix B Classification of pesticide brands per active ingredient

Table B.1: Classification of herbicides per active ingredient

Active ingredient	**Product Brand Name**
isoxaflutole	Corvus®
2,4-Dichlorophenoxyacetic acid	2,4-D LV6 , Butyrac®
acetochlor	SureStart®, Degree XTRA® , Harness®, Harness® Xtra, Breakfree® NXT ATZ
atrazine	BicepIIMagnum®, Brawl II ATZ™, Sortie™ ATZ, Trizmet™ II, Guardsman Max®
clethodim	Arrow®, Section® 2 EC, Select® 2 EC, Volunteer™
clopyralid+fluroxypyr	WideMatch®
cloransulam	FirstRate®
dicamba	Status®, Sterling® Blue
dimethenamid-P	Verdict®
fenoxaprop	Puma®
fluazifop	Fusilade®
Flufenacet	RADIUS™
Flumioxazin	Enlite®, Valor®, Valor® XLT
Fluthiacet-methyl	Cadet®
Fomesafen	Flexstar®
glufosinate	Liberty®
glyphosate	Buccaneer® Plus, Cornerstone®, Durango® DMA®, Roundup PowerMax®, Roundup WeatherMax®, Abundit® Extra, Honcho® Herbicide, Extreme®, Touchdown®
imazaquin	Scepter® 70 DG
imazethapyr	Optill® PRO
Isooctyl	Weedone® LV4 EC
MCPA	BISON® Advanced
Mesotrione	CALLISTO®
Metolachlor	Me-Too-Lachlor™ II, Matador®
Metribuzin	Authority® MTZ, Boundary® 6.5 EC, Canopy®
nicosulfuron	Accent® Q
paraquat	GRAMOXONE®
Prosulfuron	Peak®
pyroxasulfone	Zidua®, Fierce®
saflufenacil	Sharpen®
simazine	Princep®
s-metolachlor	Lumax® EZ

Table B.1 continued

Active ingredient	Product Brand Name
s-metolachlor + glyphosate	Halex® GT
sulfentrazone	Sonic®, Authority® First DF
tembotrione	Capreno®
thifensulfuron	Harmony® Extra
topramezone	IMPACT®

Table B. 2: Classification of insecticides per active ingredient

Active ingredient	Product brand name
Beta-cyfluthrin	Baythroid® XL
Bifenthrin	Capture® LFR®, Hero®
chlorpyrifos	Lorsban®
Cyfluthrin	Tombstone™
Deltamethrin	Delta Gold®
Gamma-cyhalothrin	Proaxis™
Imidacloprid	Leverage® 360
Lambda-Cyhalothrin	Warrior®
Tebupirimphos	Aztec®
Tefluthrin	FORCE® 3G
terbufos	Counter® 20G

Table B. 3: Classification of fungicides per active ingredient

Active ingredient	Product brand name
Azoxystrobin	QUILT®
Picoxystrobin	Aproach®
pyraclostrobin	Headline®
Tebuconazole	Prosaro®
Tetraconazole	Domark®
Trifloxystrobin	Stratego® YLD

Appendix C Panel Data Regression Analysis

The data collected from farmers were observations over time and space. Therefore, we treat our data as panel data because the observations are two-dimensional. As described in chapter four, most farmers provided field data with a corn-soybean rotation. Thus, we have created a dataset for each crop. The objective of this analysis was to quantify the impact of cover crops on corn and soybean yields by controlling for other variables. In this appendix, we will first define the dependent and independent variables, then present the model used, and finally display the results.

1. Dependent variables

The dependent variables considered in this analysis are the yields of corn and soybeans. The table C.1 displays the descriptive statistics for both variables.

Table C. 1: Descriptive Statistics for Corn and Soybean Yields (in bu./ac)

	Mean	Std. Dev	Min	Max	Count
Soybean yield	54.25	10.70	25	74	110
Corn yield	171.93	39.29	63	264	116

2. Independent variables

The independent variables of our model include the time dimension, the cover crop regime, tillage regime, soil order, and field slopes. Nitrogen application was also included in the corn dataset only. A description of each variable is provided in this section.

- Time dimension

Most farmers provided field data for the past five years, from 2009 to 2013. Therefore, we have created four time period dummies: $y10$ for 2010, $y11$ for 2011, $y12$ for 2012 and $y13$ for 2013. The base time period is 2009.

- Cover crop regime

From the data collected, we know if the field had cover crops or never had cover crops in it. We created a dummy variable called cc_reg. If cc_reg equals one, cover crops were planted in the field and therefore we want to test whether corn or soybeans yields were impacted by the effect of cover crops. If cc_reg equals zero, then cover crops were not planted before the cash crop growing season.

- Tillage regime

The observations were classified into three type of tillage; conventional tillage (CT), no-tillage (NT) and other conservation tillage (OCT). Two dummy variables were created for no-tillage (NT) and other conservation tillage (OCT). If NT equals one, that means that the field in that year was under no-till management, and zero otherwise. If OCT equals one, then that field was under other conservation management such as reduced tillage or strip tillage, and zero otherwise. If the two variables are equal to zero, that means that the field was under conventional tillage.

- Soil order

By classifying the soil series into their soil orders, we ended up with five different soil orders. Therefore, we have created four dummy variables for four soil orders: alfisol (alf), entisol (ent), vertisol (ert), and inceptisol (ept). The base soil order is mollisol.

- Field slope

Four field slope classes were collected from our data. Therefore, we have created three slope class dummies for field slopes 2-6%, 6-12%, and 12-20%. The base field slope class is 0-2%.

- Nitrogen application on corn

Nitrogen application on corn was calculated for each year when corn was planted. This variable is included in the corn yield model because it has an effect on corn yields. Table C.2 display the descriptive statistics for nitrogen application on corn.

Table C. 2: Descriptive Statistics for Nitrogen Application (in lbs./ac)

	Mean	Std. Dev	Min	Max	Count
N application	194.40	42.61	120	296	116

3. Fixed effects model

A fixed effects model is used because we assume that the omitted variables are correlated with the independent variables. The possible omitted variable in this model are the average temperature and precipitation for each field, or also the level of management expertise of a farmer. The fixed effect model used for corn yield is given by equation C.1.

Equation C.1:

$$\begin{aligned} Corn\_yield_{it} = {} & \delta_0 + \delta_1 y10 + \delta_2 y11 + \delta_3 y12 + \delta_4 y13 \ + \ \beta_1 cc\_reg_{it} + \beta_2 alf_{it} \\ & + \beta_3 ent_{it} + \beta_4 ert_{it} + \beta_4 ept_{it} + \beta_5 slope2-6_{it} + \beta_6 slope6-12_{it} \\ & + \beta_7 slope12-20_{it} + \beta_8 NT_{it} + \beta_9 OCT_{it} + \beta_{10} N\_app_{it} + \alpha_i + u_{it} \end{aligned}$$

In the equation C.1, i denotes the farm number and t denotes the time period. For the soybeans analysis, the equation is the same except that the nitrogen application is not included. The results for the two regression provided in the next section were produced using STATA 12.1.

4. Results

Table C.3 presents the results of the multiple regression analysis performed for corn and soybean yields. The variable of interest in both regressions is the cover crop regime. As you can see in the table C.3, the results are statistically insignificant and therefore not conclusive. This is due to the low number of observations in the data collected. The variable for entisol was omitted from the soybean model because there was only one entry of entisol in the soybean dataset.

Table C. 3: Regression Results

CORN		**SOYBEANS**	
Variable	Coefficient	Variable	Coefficient
y10	-14.23	y10	-0.82
	(10.80)		(2.56)
y11	-14.12	y11	-5.36**
	(8.93_		(2.42)
y12	-65.94***	y12	-7.48***
	(11.53)		(2.59)
y13	11.41	y13	-4.97**
	(8.95)		(2.43)
cc_reg	7.45	cc_reg	3.74
	(9.44)		(2.53)
alf	-16.77	alf	1.07
	(16.10)		(4.59)
ert	-31.52	ert	3.61
	(21.79)		(6.37)
ept	-3.53	ept	1.45
	(39.69)		(5.88)
ent	-0.48	ent	omitted
	(46.58)		
slope2-6	13.07	slope2-6	-8.03
	(15.77)		(4.08)
slope6-12	-5.76	slope6-12	0.85
	(19.00)		(5.34)
slope12-20	39.52	slope12-20	-19.10***
	(26.54)		(6.26)
NT	-32.17	NT	-9.23**
	(30.43)		(4.57)
OCT	-72.69*	OCT	6.73
	(40.53)		(9.70)
N_app	-0.16		
	(0.14)		
constant	263.96***	constant	65.58***
	(42.09)		(5.25)
No. observations	116	No. observations	110
R-squared	0.24	R-squared	0.18
F value	1.62*	F value	2.27***

Standard errors are reported in parentheses.

*, **, *** indicates significance at the 10%, 5%, and 1%, respectively.